PETROLEUM AND NATURAL GAS.

NATURAL GAS IN NORTH DAKOTA.

By A. G. LEONARD.

The gas wells of North Dakota are confined mostly to Bottineau County, in the north-central part of the State, but gas has been found near Crosby, in Williams County, in the northwestern part of the State, and in Lamoure County, in the southeastern part. In these three counties there are at least 25 gas wells. (See Pl. I.)

Most of the wells in Bottineau County are in the vicinity of Westhope and have depths ranging from 147 to 202 feet. Gas was first struck on July 3, 1907, in a well drilled for water on the Parker farm, 9 miles south of Westhope. The Great Northern Oil, Gas and Pipe-Line Company was organized to prospect and develop the field and sunk a number of wells. Lately the company has been reorganized under the name of the North Dakota Gas Company. This company has eight wells, and the gas from five of them is piped to Westhope, where it is used for heating, cooking, and lighting. The company has 20 miles of pipe line, a 4¼-inch steel pipe carrying the gas into town, and a 3-inch pipe distributing it in the streets. The gas has been used in Westhope since the fall of 1909 and there are now 120 consumers, many of them farmers who live along the line. The gas sells for 30 cents a thousand feet in winter and 40 cents in summer. It is used with a mantle and gives an excellent light.

An analysis of the gas made by Prof. E. J. Babcock, of the University of North Dakota, shows the following results:

Analysis of natural gas of Bottineau County, N. Dak.

Hydrogen	0. 5
Methane	82. 7
Ethylene and other illuminants	. 2
Carbon monoxide	1. 2
Oxygen	3. 0
Nitrogen	12. 4

The oxygen and nitrogen are probably in the form of air.

B. t. u. (calculated), 886 per cubic foot.

The gas shows a bluish tint when blown off at the well and has almost no odor. The rock pressure at the different wells ranges from 55 to 65 pounds per square inch. The flow of one well, which has a 6¼-inch casing, was 3,200,000 cubic feet in twenty-four hours. Other wells have yielded from 400,000 to 1,000,000 cubic feet in twenty-four hours. The gas escapes from the well with a loud roar, the noise made by one well having been heard, it is said, in a town 4 miles distant.

The wells near Westhope are in secs. 3, 11, 12, and 13, T. 161 N., R. 81 W.; secs. 34 and 35, T. 162 N., R. 80 W.; and secs. 9 and 10, T. 161 N., R. 80 W.

There is a gas well 200 feet deep in the town of Russell, 17 miles south of Westhope; one near Bottineau, and another about 6 miles south of Bottineau.

The village of Lansford, in the southwest corner of Bottineau County, uses gas piped from wells 5 miles northeast. Gas was discovered here in September, 1909, by drillers boring a well for water. Three wells have been put down, ranging in depth from 200 to 210 feet. One report gives the first pressure as 64 pounds, another as 72 pounds per square inch. The pressure was so great that it blew large quantities of sand from the hole, together with pebbles, small bowlders 5 or 6 inches in diameter, pieces of wood, and rounded, waterworn fragments of lignite. For some months the normal pressure at the wells has remained at 18 to 20 pounds. The wells are located in secs. 28 and 29, T. 160 N., R. 82 W. The record of the well in sec. 29 is as follows:

Record of gas well in sec. 29, T. 160 N., R. 82 W., Bottineau County, N. Dak.

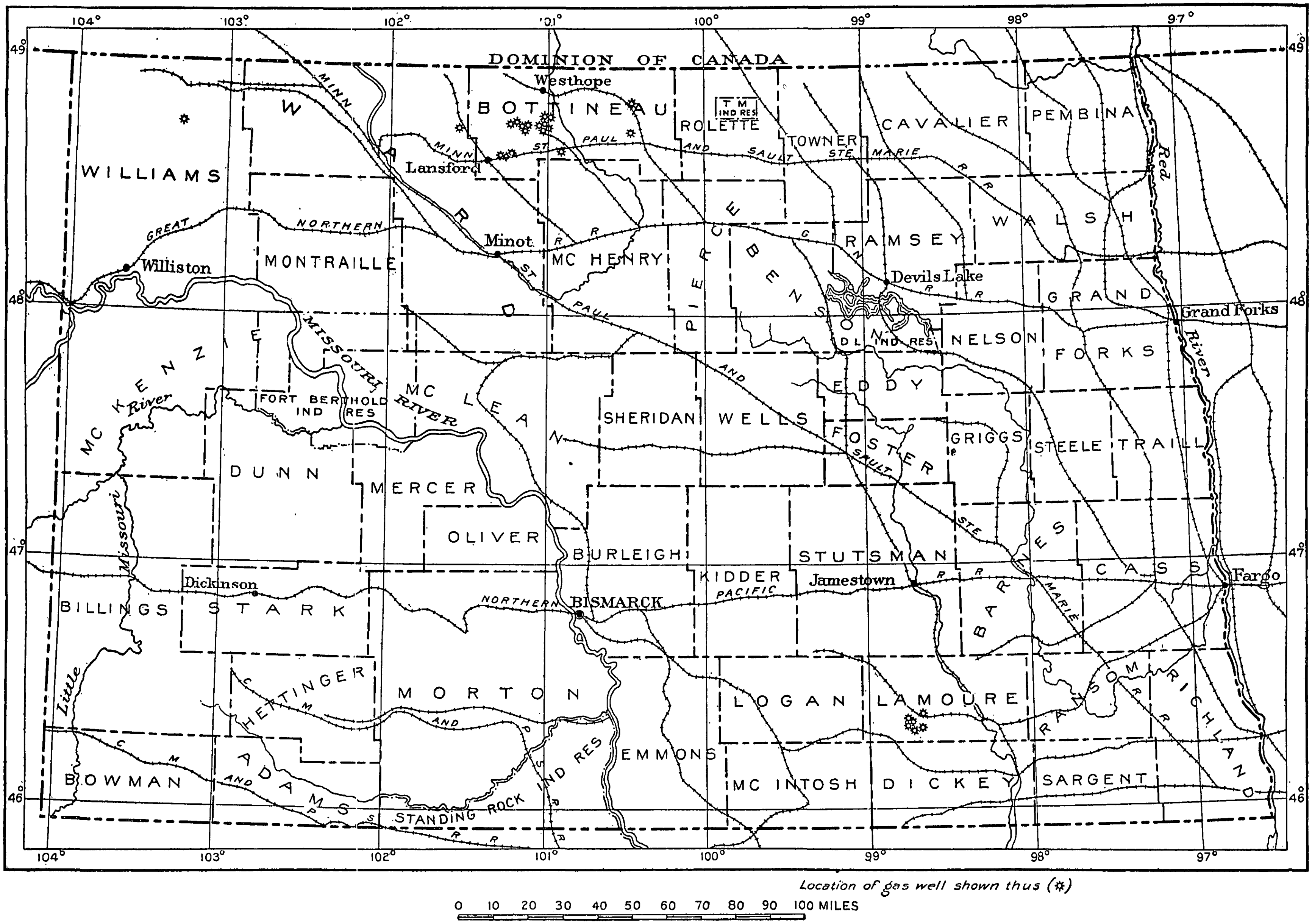
	Feet.
Clay, yellow	20
Clay, blue	20
Sand, with some water	46
Clay, sandy, light blue, containing powdered lignite	75
Clay, blue, free from sand	40
Gas sand, containing pebbles, small bowlders, and lignite fragments struck at 201 feet.	

Analysis of natural gas from Lansford, N. Dak.

[By Prof. E. J. Babcock.]

Carbon dioxide	0.00
Illuminants	.10
Oxygen	7.10
Carbon monoxide	.30
Methane	71.15
Hydrogen	4.74
Nitrogen	16.61

This sample evidently contained some air derived from the pipe or introduced in collecting.



MAP OF NORTH DAKOTA SHOWING LOCATION OF GAS WELLS.

Gas is reported to have been found near Mohall, at the eastern edge of Ward County, and also in the vicinity of Crosby, in northeastern Williams County.

The North Dakota Gas Company is drilling a deep well 9 miles south of Westhope, with the hope of striking gas at greater depth in the Cretaceous formations. The hole was put down to a depth of 1,370 feet in 1908, when the work was stopped and was not resumed until June, 1910. An effort will be made to reach the Dakota sandstone, which in some regions in Canada contains much gas. An oil-well borer of the usual American type is being used, with a derrick built on the ground. The boiler is fired with gas from a near-by well.

The following is a record of this deep well:

Record of gas well 9 miles south of Westhope, N. Dak.

		Ft.	in.
Soil		2	
Clay, yellow, and gravel		30	
Clay, blue		122	
Gravel with sand below (no flow of gas)		16	
"Slate," white		35	
Sand seam, black		3	
Shale, soft, blue (caving)	Pierre (?)	242	
"Slate," black	Pierre (?)	50	
Shale, blue (caving)	Pierre (?)	205	
Rock, yellow, hard (limestone)	Niobrara (?)		5
Shale, blue	Niobrara (?)	145	
Shale, sandy		10	
Shale, blue, to bottom (Benton?)		510	
		1,370	5

The gas of the Bottineau field occurs in a bed of sand at the base of the drift, which is from 150 to 200 feet thick. The sand is rather fine, with rounded grains, and of a greenish-black color, due apparently to decomposing carbonaceous matter. In places this sand contains pebbles, small bowlders, and considerable lignite in fine particles and waterworn fragments. The sand bed containing the gas ranges in thickness from 20 to 30 feet. The gas accumulates in this sand as a reservoir and is prevented from escaping by the compact clay of the overlying drift.

The source of the gas is probably the Cretaceous shales and sands underlying the drift. The gas occurs in quantities so large and has been found at so many widely separated places that its source can hardly be the organic material contained in the drift itself. Fifteen miles northwest of Westhope, in Canada, the Pierre shale appears at the surface in places, and for the past twenty-five years gas is reported to have been noticed bubbling up and escaping from the streams. Recently gas has been struck in shale in two wells in that locality, where it appears to accumulate in the joint cracks and crevices so common in the Pierre.

The Cretaceous formations underlying the glacial drift in the Bottineau field are the Pierre, Niobrara, Benton, and Dakota, named in order from above. Which one of these formations is the source of the gas has not been determined, though the deep well mentioned above has penetrated the Pierre and Niobrara without striking gas. In Canada gas occurs in the Judith River formation (which is the time equivalent of part of the Pierre shale) at Medicine Hat, and in the Dakota (?) sandstone at Bow Island and elsewhere. The gas of Lamoure County, N. Dak., comes from artesian wells in the Dakota sandstone. The Niobrara formation, at its outcrops along the western edge of the Red River valley in the Pembina Mountains, contains traces of organic remains and has a strong odor of petroleum when freshly exposed. It seems probable, therefore, that one of these Cretaceous formations is the source of the gas, which has been formed from the organic remains embedded in it.

A well drilled at Minot struck at a depth of 200 feet a strong flow of a noncombustible gas, which was found by analysis to be mostly nitrogen combined with about 7 per cent of oxygen. The well is reported to have produced 3,000,000 cubic feet or more of gas a day.

At the close of 1908 six artesian wells in Lamoure County, having depths of 1,150 to 1,450 feet, yielded gas. The gas from one of these wells supplies part of the power and heat for the electric-light plant in Edgeley; that from the others is used for domestic purposes by the owners of the wells.

THE SAN JUAN OIL FIELD, SAN JUAN COUNTY, UTAH.

By H. E. Gregory.

ACKNOWLEDGMENTS.

The exploration of the San Juan oil field whose results are here reported covered only three days in the later part of July, 1909—a period of time manifestly too short for detailed study—and the data here presented were obtained largely through courtesies extended by Mr. E. L. Goodridge, of the San Juan Oil Company, and Mr. A. L. Raplee, of Bluff.

LOCATION.

The boundaries of the San Juan oil field have not been determined. The scene of the present development is along Limestone Creek, 25 miles west of Bluff, San Juan County, Utah, and the claims that have been staked are included in an oval area which has a northeast-southwest axis of about 30 miles and a northwest-southeast axis of 20 miles and is divided into two nearly equal parts by the canyon of San Juan River. (See Pl. II, p. 22.)

The oil field is far removed from market and from sources of supplies. Freight may reach Goodridge, a post-office and town site recently established on San Juan River, from Dolores or Mancos, Colo.; from Farmington, N. Mex.; or from Thompson, Utah—all on the Denver and Rio Grande Railroad. The bridge across San Juan River at Goodridge furnishes a southern outlet to the Santa Fe Railway at Gallup, N. Mex., and Holbrook, Ariz. The distance from Goodridge to Dolores by way of Bluff and along San Juan River and McElmo Creek is 106 miles; to Mancos it is about the same; to Farmington, along the San Juan, it is 110 miles; to Thompson it is 158 miles. The distance from Goodridge to Gallup, on the Santa Fe Railway, by way of Chin Lee and Ganado, is 175 miles. All these routes could be made satisfactory for freighting without prohibitive expense. So far as the topography is concerned, the most feasible route for a pipe line is probably up Chin Lee Wash to Ganado, thence down Pueblo Colorado Wash to Holbrook, a distance of about 160 miles. For nearly half this distance the oil would flow by gravity. Bluff is a Mormon settlement where fruit and alfalfa are raised by irrigation from San Juan River. This village is 25 miles from Goodridge and is at present the only available source of small supplies within a moderate distance. At considerable expense a fairly good road has been constructed from Bluff to the oil field. The road crosses Comb Wash at Navajo Springs, which furnish excellent water.

CLIMATE.

The region is arid. The precipitation is indicated by records at Hite, Utah, on Colorado River, elevation 3,000 feet, 50 miles northwest of Goodridge, and at Aneth, Utah, 50 miles east. At Hite, where complete records for 1903, 1904, 1905, and 1907 are available, the mean precipitation for these years is 7.05 inches; the least rainfall, 3.12 inches, fell in 1903, and the most, 12.36 inches, in 1905. The seasonal means are—winter, 1.26 inches; spring, 2.26 inches; summer, 1.51 inches; fall, 2.02 inches. The variation in precipitation is indicated by the facts that the records for May range from 0.23 to 1.58 inches, those for August from 0.00 to 1.31 inches, and those for November from 0.00 to 3.83 inches. The few records at Aneth indicate a rainfall similar in amount and irregularity. The mean temperatures at Hite from 1900 to 1903 are—winter, 38°; spring, 60°; summer, 83°; fall, 60°. At Aneth a maximum of 104° and a minimum of −10° has been measured.

VEGETATION.

The small rainfall precludes the possibility of forest growth, hence the region is bare of trees except scattered cottonwood and willow along San Juan River and cedar and piñon on the higher ridges, mostly above 6,000 feet. Marketable timber is reported from Elk Ridge and Abajo Mountain, farther north. Grass is scarce, and partly on this account and partly on account of the lack of drinking water neither Piutes, Navajos, nor American stockmen make full use of this district as grazing land. Although the grass is as nutritious and as plentiful as it is in parts of the Navajo Reservation farther south, now used by sheep herders, prospectors working in this field could not safely rely on local feed for their animals. The calcareous soil is very fertile when water is applied to it, as is shown by the highly successful agriculture and horticulture at Bluff. The only available sources of water, however, are San Juan River and wells; and the wide extent of bare rock surface, the absence of alluvial plains along the smaller tributaries and of alluvial fans at the base of the higher cliffs, and the deeply dissected interstream spaces limit available sites for irrigated crops to patches only a few acres in extent. The country is adapted to stock raising rather than to agriculture.

SUPPLIES, FUEL, AND LABOR.

The prices of groceries, hardware, and other supplies at Bluff are in general those charged at the railroad plus freight. Hay and grain cost about the same as at Gallup and Cortez. The freight from Dolores to Bluff is $7.50 and from Bluff to Goodridge $1 a hundred pounds.

Fuel for boilers and for domestic use consists at present of driftwood brought down by San Juan River when at flood stage. Logs hauled from the higher mesas are also used. The supply of fuel from these sources is small, and if the field is to be developed the well must yield sufficient oil for fuel or coal must be brought in. The most available coal beds are those of the Durango field of Colorado, 100 miles to the east, and of the Black Mesa on the Navajo and Hopi reservations, Arizona, 60 miles to the south.

Labor for the most part will have to be brought in, although under skillful leadership the Indians could be relied upon to supply the demand for labor in part. The Navajos particularly are intelligent and faithful workers.

LAWS CONTROLLING CLAIMS.

It should be borne in mind that the area included in the oil field is subject to two jurisdictions. That part north of San Juan River is under the control of the General Land Office and on October 4, 1909, was withdrawn from "all forms of location, settlement, selection, filing, entry, or disposal under the mineral or nonmineral public land laws." "Claims existing and valid on this date may proceed to entry in the usual manner." Oil claims south of the river are partly on the Western Navajo Reservation, and their location is subject to the regulations formulated by the Office of Indian Affairs.

TOPOGRAPHY.

The San Juan oil field is part of the Colorado Plateau, a physiographic province with altitudes ranging from 5,000 to 7,000 feet, composed largely of flat-lying sedimentary rocks ranging in age from Carboniferous to Cretaceous. The river valleys are canyons cut in solid rock. The elevations are either mesas and buttes remaining after the erosion of the surrounding areas or are volcanic necks and lava-capped mesas. Much bare rock is exposed at the surface. The area included in the oil field has an altitude of 4,000 to 5,000 feet and differs in topography from the typical Colorado Plateau only in that the rocks are folded into well-marked synclines and anticlines.

The region is drained by San Juan River, a tributary to the Colorado and through this part of its course a permanent stream. The northern tributaries are Comb Wash, Limestone Creek, Johns Canyon, and Grand Gulch, none of which flow permanently. The sands of Comb Wash are, however, saturated with water, and springs issue from the rock floor at several places along the other tributaries. The water in San Juan River is usually very muddy but is otherwise of good quality, and the tributary streams from the north, though alkaline, may be safely used for domestic purposes. Gypsum Creek, which enters the San Juan from the south, flows more or less throughout the year, but its water is avoided by men and animals alike. The immediate valley of the San Juan in this area is a canyon. From the narrows in the anticline east of Limestone Creek to Raplee's camp the canyon walls are 300 to 500 feet high. At Raplee's and at Goodridge the river is accessible and at the latter point the sandstones overlying the Carboniferous rocks have been removed, furnishing a roadway to the canyon almost to the water's edge. At this place a bridge has recently been constructed, the only bridge crossing the San Juan for a distance of over 200 miles. Below the bridge the river occupies a narrow canyon, which meanders in a series of nearly closed curves or "goose necks." The precipitous sides of the San Juan Canyon attain at Honaker trail a measured depth of 1,300 feet. Grand Gulch is a steep-walled rock canyon 40 miles long which forms one of the main lines of drainage from the Orejas del Oso (Bear's Ears) Mountains. The topography here is so broken that under present conditions the expense of transporting well outfits into this valley is hardly justifiable. Limestone Valley carries the run-off from the region between the East Anticline and Cedar Ridge. Its upper part is a wide valley cut in sandstone; its lower part is a box canyon.

The most prominent topographic features in that part of the oil field which lies north of San Juan River are East Anticline and Cedar Ridge. East Anticline is a fold 6 to 8 miles wide, on the west flank of which are upturned the red rocks of Limestone Valley on the west and the serrate hogback ("the Comb") on the east. Uneroded remnants of overlying rocks stand here and there above the exposed top of the fold, but the general surface of the ground corresponds with the position and dip of the limestone cap. Cedar Ridge is a broad mesa terminating on the south and east in precipitous cliffs 400 to 600 feet in height. This ridge is the uneroded portion of West Anticline and stands 14 miles northwest of East Anticline. At the base of Cedar Ridge and in the syncline drained by Limestone Creek are many buttes and pinnacles of grotesque shape, 100 to 300 feet in height, cut from the red sandstone and shale overlying the limestone of East Anticline. South of the river East Anticline flattens and disappears and the continuation of Cedar Ridge is represented by pinnacles, monuments, and fluted buttes, constituting one of the most remarkable groups of erosion forms to be found in the United States. The smaller buttes, both north and south of the river, are made of strata represented in Cedar Ridge, the particular strata involved depending upon the height and the position of the butte. The general topographic expression of the area in which most of the oil prospecting has been done is indicated in Plate II, page 22.

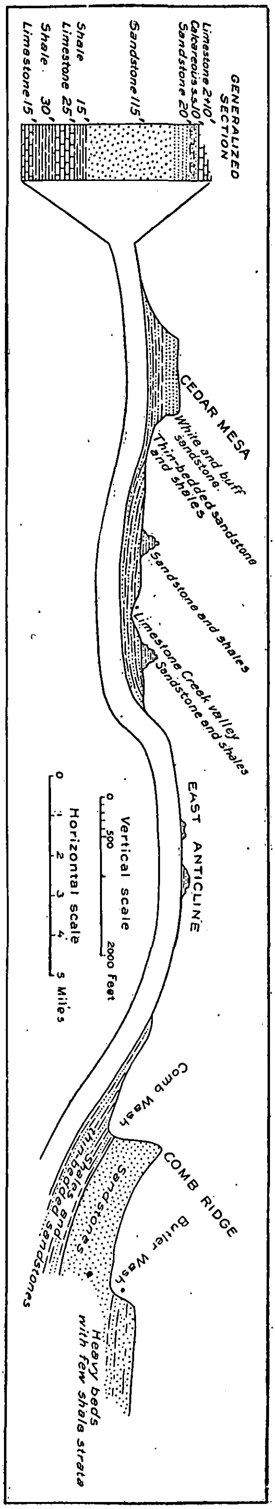


FIGURE 1.—Sketch east-west structure section across the San Juan oil field.

GEOLOGY.

STRUCTURE.

In the oil field flat-lying sedimentary rocks found east, north, west, and south, are folded to form two anticlines with a broad intervening syncline, a crumpling apparently unaccompanied by faulting. The rock systems that took part in the disturbance and are now exposed by erosion are the Carboniferous, Triassic, and Jurassic. Approximately 2,000 feet of sedimentary rocks above the fossil-bearing Carboniferous are in sight. The hogback ridge which forms the east bank of Comb Wash and continues south and west along Gypsum Valley to the vicinity of Cha-ezkla Rock appears to represent the steep downfolded eastern side of a dome or monocline which formerly extended westward toward Colorado River. This giant dome was modified by smaller folds, two of which, with axes trending N. 20° E., and thus approximately parallel to the bordering hogback, constitute the fundamental structural features of the San Juan oil field. Nearly all the wells so far drilled are located along the syncline.

STRATIGRAPHY.

GENERAL RELATIONS.

The measured sections to be given show the character and order of deposition of the strata in the vicinity of the oil field.

The rock walls bordering San Juan River at Bluff are assumed to be of Jurassic age, the cliffs near "The Twins" being of La Plata sandstone and the McElmo formation appearing farther up the river. It is probable that the Dolores formation (Triassic) forms the base of the cliffs and is represented in the well section at Bluff. In the section at the Goodridge bridge and at Honaker trail the upper Carboniferous (Pennsylvanian) is well exhibited and the strata in Cedar Ridge and in the valley of Limestone Creek are believed to include the Permian and a large part of the Triassic. Data for distinguishing the particular formations constituting these systems were not obtained, but the rocks are well exposed, and detailed work would doubtless give a satisfactory interpretation of the geologic history of this area in late Paleozoic and early Mesozoic time.

THE OIL SANDS.

Eight distinct oil-bearing sands are represented in the canyon section. These sands are locally called the Baby, Goodridge, No. 3, Mendenhall, Amber, Goose Neck, Blue Shale, and Honaker sands.

At all places examined the rock containing the oil is practically identical in character at each horizon. It is a white sandstone, probably bleached, fine grained, friable, generally porous, has calcareous cement, and weathers with concretionary structure. All the beds are more or less fossiliferous and in places consist of solid masses of shells. The porosity of the oil sands is apparently due to the removal of calcareous fossils. The rock overlying the Baby sand is a dark-blue, exceptionally durable limestone; that overlying the Goodridge sand is a fossiliferous, firm limestone, 3 feet thick. One of the striking features of this region is the relative indestructibility of these thin beds of limestone, so that the most widespread surface rock, the one which in large part controls the surface form, is a thin "cap rock" of limestone. This limestone cap has prevented the escape of the oil upward and has thus allowed it to accumulate in the porous sand.

Section at "The Twins" at Bluff, Utah.

[Thickness estimated.]

	Feet.
1. Sandstone, massive, cross-bedded, fine grained. Forms boundary wall of San Juan Valley; most prominent cliff maker of this region; weathers into buttresses; forms upper half of "Twins;" forms roof of cliff dwellings; water seep at its base. This sandstone on a fresh surface is white with slight pinkish tone, showing quartz grains with calcareous cement (La Plata?)	100–200
2. Sandstone and soft shale in regular bands. Shale sandy, chocolate-brown, with thin layers (3 to 8 inches thick); sandstone (surface stained brown) white with greenish tones; beds 2 to 10 feet thick; irregular partings; rock used for houses in the village	70

	Feet.
3. Shale (sandy in places), thin sandstones, and occasional gypsum beds; brick-red with greenish mottling; dip of beds various and irregular	50
Well section at foot of "The Twins."	
4. Sandstone, dark brick red, thin bedded, with shale below and above	200
5. Sandstone, white to yellow, cross bedded; mostly fine even-grained with pebbles of concretionary limestone. Lower 200 feet is dark red and even-grained; some of the beds are calcareous and apparently all are cemented with lime. Same as sandstone forming "Comb" at Comb Wash	800
	1, 220–1, 320

Section from top of Cedar Point to bottom of San Juan Canyon at foot of Honaker trail.

	Ft.	in.
1. Sandstone, white to reddish brown, in beds 4 feet to 40 feet thick. Thinner beds break into slabs with shale partings; heavier beds remain massive. Cross-bedding is rare. Forms top of Cedar Ridge and part of it forms the "Bottle," the "Sultan of Turkey," the "Hen," etc., which rest on pedestals of shale and sandstone consisting of No. 2 above and lower strata (thickness estimated)	300	
2. Shale, extremely fissile, irregularly bedded, dark red to purple, sandy, forming uneven surface on which rests massive sandstone of the cliff proper; contains veins of gypsum and lime	10	
3. Limestone, blue-white, with arenaceous nodules	5	
4. Sandstone, dark red, with some interbedded shale	30	
5. Sandstone, gray, firm, thinly foliated, weathers dark purple, quite unlike anything else in region	6	
6. Sandstone, pale red, shaly, cross-bedded	5	
7. Sandstone, gray; white background, black spots; in places fine conglomerate; very resistant top part cross-bedded	2	
8. Limestone, purple-blue, nodular, thinly laminated, with small brown siliceous concretions	2	
9. Sandstone and shale, red, with nodular and lens-shaped concretions of gypsum and lime	6	
10. Shale and shaly sandstone, red, irregularly alternating so as to form steps; fine grained, calcareous, pitted; contains numerous white bleached spots	150	
11. Sandstone, chalk-white, very fine, calcareous; forms top of bench		4
12. Sandstone and sandy shale, red; varying degrees of hardness result in forming a series of little benches	55	
13. Limestone, light blue, nodular; caps a bench		6
14. Shale, dark red, with sandstone weathering with pits and mottled by patches of light blue (result of leaching?)	21	
15. Limestone, light blue, nodular		4
16. Sandstone, red, highly calcareous	10	

	Ft.	in.
17. Sandstone, dark red, calcareous, shaly in part; weathers with numerous pits one-eighth inch, more or less, in depth	20	
18. Limestone, dense, dark blue, cherty (chert lenses locally reddish brown). Contains many black twiglike marks simulating fossils made up in part of nodules of limestone; forms definite bench; forms top of East Anticline	2	
19. Shale, red, sandy, calcareous cement with occasional thin white leached band	50	
20. Sandstone and shale, calcareous; surface between base of Cedar Ridge and top of canyon wall is partly covered and was not carefully measured; appears to be two beds, 20 and 15 feet	35	
21. Sandstone, pinkish white, calcareous	10	
22. Sandstone, white or gray, forming rim of canyon where it begins to deepen rapidly	20	
23. Sandstone and red shale, with calcareous cement; sandstone in beds 20 to 40 feet thick	115	
24. Shale, red, sandy, lime cement	15	
25. Limestone, blue, cherty, with shale partings	25	
26. Shale, blue and purple, calcareous	30	
27. Limestone, blue-gray; contains reddish-brown chert fragments and lenses; abundantly fossiliferous (see list, pp. 19–20)	15	
28. Shale, bluish gray, calcareous	10	
29. Covered	20	
30. Conglomerate made of pebbles of limestone one-eighth inch to 1 inch in diameter; contains fossils (see list, pp. 19–20)	10	
31. Shale, purple and red	20	
32. Limestone; one bed 20 feet thick, blue-gray, with much chert or flint, some of it red; brown jasper; fossils (see list, pp. 19–20)	30	
33. Shale, bituminous, black, very finely divided; smells of oil	2	
34. Limestone with some thin arenaceous beds; contains chert and some fossils	120	
35. Sandstone, white or gray, fine grained, calcareous	10	
36. Limestone in beds 1 foot to 6 feet thick	50	
37. Shales, calcareous and arenaceous	30	
38. Sandstone, calcareous, or arenaceous limestone, in places banded, elsewhere massive; large part, especially near bottom, consists of pinkish sandstone; about two-thirds way up are thin regular bands of blue limestone and chert; top is blue limestone, richly fossiliferous (see list, pp. 19–20)	145	
39. Shale and arenaceous limestone with black chert	8	
40. Shale, sandy, and black bituminous shale, very thinly foliated; has odor of oil	4	
41. Limestone, blue, thin bedded	10	
42. Sandstone and shale, more or less modified by chemical action; contains sulphur in pockets and rock is whitened	25	

	Ft	in
43. Limestone, thin bedded, full of rounded concretions and irregular lenses of jet-black chert; layers containing chert are cross-bedded, folded, and seem to be separated from beds above by an erosional unconformity; contains numerous brachiopod fossils in upper part	25	
44. Sandstone, pink, calcareous	7	
45. Limestone, dense, blue	15	
46. Shale, white, sandy, with buff sandstone	7	
47. Limestones, blue-gray, arenaceous near bottom; full of lenses and irregular beds of jet-black flint and chert	70	
48. Limestone, black, very hard		3
49. Sandstone, yellow-white, shaly, cross-bedded	8	
50. Limestone, blue, with interbedded calcareous shale	20	
51. Limestone, nodular, shaly, buff to blue; abundantly fossiliferous	10	
52. Limestone, blue, beds 12 to 14 inches, separated by shale; contains fossils	7	
53. Shale, bluish yellow	4	
54. Limestone, blue-gray, nodular, shaly, with abundant fossils (see list, pp. 19–20)	5	
55. Shale, bituminous, black, fissile		4
56. Limestone, blue, with arenaceous bands	20	
57. Sandstone, yellow	5	
58. Limestone, blue, with chert	10	
59. Sandstone, white to buff, very fine grained	4	
60. Shale, bituminous, fissile, black		1
61. Limestone, dark blue, with chert top; contains crinoid stems	5	
62. Sandstone, cream-colored, calcareous	2	
63. Limestone, dark blue, with flint	3	
64. Limestone, white, full of cavities filled with calcite	4	
65. Limestone, thin bedded, dark blue, with numerous cherty nodules and lenses	5	
66. Limestone, light blue	5	
67. Limestone, dark blue, thin bedded, with chert and flint lenses	30	
68. Sandstone, calcareous, dark yellow and blue	15	
69. Limestone, dark blue, in beds 5 to 6 feet thick	20	
	1,740	10

Fossils collected from the beds numbered 27, 30, 32, 38, and 54 of the Honaker trail section were submitted for identification to Professor Schuchert, who reports: "All the lots are of the Pennsylvanian. The horizon is the widely distributed Pennsylvanian, but apparently is not so low as the Pottsville, nor is the horizon near the top of the series." The species named below were identified:

Fossils from Honaker trail section.

Lot 1.
- Productus cora.
- Reticularia perplexa.
- Spirifer rockymontanus.
- Spirifer cameratus (rare).
- Composita argentea.

Lot 2.
Productus sp. undet.
Orbiculoidea cf. nitida (very common).

Lot 3.
Orthotetes crassa.
A fish tooth of Deltodus sp. undet.

Lot 28.
Septopora biserialis.
Productus nebrascensis.
Pugnax utah.
Spiriferina cristata.

Section down San Juan River from Goodridge bridge, just below mouth of Gypsum Creek.

	Ft.	in.
1. Sandstone, red to chocolate-brown, with thin sandy shale, fine grained, limy in places; rocks for several hundred feet above and back from rim apparently the same (estimated).	200	
2. Limestone, blue, hard; weathers rough; contains shell fragments	3	
3. Sandstone, red, brown as No. 1, but fresh rock reveals white and yellow tones in some beds	28	
4. Sandstone, white (Goodridge oil sand), fine, friable; weathers with concretionary structure on top; all more or less calcareous and lower 6 feet solid mass of fossil fragments	46	
5. Shale, purple	2	
6. Sandstone, white, friable	3	
7. Shale, brown to red, sandy, with few streaks of buff and blotches of bluish white	30	
8. Limestone, dense, blue-white; abundant fossil fragments; in places seemingly oolitic and elsewhere flint lenses	15	
9. Shale, gray		8
10. Shale, purplish brown	1	4
11. Sandstone, reddish pink, with purple tone in top part; limy and mass of fossils at bottom; shaly and weathers in pillars, balls, etc	8	
12. Sandstone, bright chocolate-red, calcareous, more or less shaly; certain bands weathering in pillars, etc	50	
13. Sandstone, white-gray, porous, more or less calcareous; irregularly bedded	6	
14. Shale, purplish red, dark brown, marly	6	
15. Sandstone and shale, bright red, thin bedded; weathers with pitted surface; calcareous cement	24	
16. Limestone, hard, blue-black	3	
17. Sandstone and sandy shale, red to chocolate, with a 2-inch band, more or less irregular, of black cherty limestone	15	
18. Chert, black, in irregular lenses continuing for several hundred feet; fossils		3
19. Shale, sandy, gray, laminæ exceedingly irregular; nodules, clay patches, etc.; few chert lenses	15	
20. Conglomerate, pebbles one-eighth to 1 inch, mostly of red shale; gray limestone and shale; contains crinoids, bryozoans, corals, and a few brachiopods	4	
21. Shale, red and purple	2	

	Ft.	in.
22. Sandstone and shale, red	40	
23. Sandstone, pink-white	15	
24. Limestone, blue, fossiliferous	10	
25. Shale, blue, purple, pink, and red, and crumbly sandstone.	25	
26. Limestone, blue, full of great masses (3 inches to 3 feet) of jasper-colored flint; body of rock made up largely of fossils (brachiopods, bryozoans?, crinoids); estimated thickness.	20	
27. Shale, red; estimated thickness	30	
28. Limestone, gray, weathers easily; has some jasper-colored chert; otherwise consists of fossils (excellent specimens might easily be obtained). Fossils weather red and chocolate; estimated thickness	15	
	617	3

DEVELOPMENT OF THE OIL FIELD.

The existence of "oil seeps" in the San Juan Canyon has been known for many years. The first location was made in the spring of 1882 by Mr. Goodridge, who made the hazardous trip through the San Juan and Colorado canyons from Bluff to Lees Ferry with the loss of one boat. The first well (crossing No. 1) was drilled during 1907–8 and oil was struck on March 4, 1908. From that date until the spring of 1909 development was rapid, but in July, 1909, drilling was in progress at only one well in the entire field. On the whole, the drilling has not been skillfully done, and it is reported that tools have been lost at nearly every well drilled in the field. The filing of claims has kept far ahead of developments, as is indicated by the fact that nearly 10,000 locations have been recorded at Monticello, the county seat of San Juan County.

Statistics regarding wells in the field in July, 1909, kindly furnished by Mr. Goodridge, are given below.

Wells drilled in San Juan oil field.

1. Crossing No. 1 well of Oil Company of San Juan; 220 feet deep; gusher, oil spouting to height of 70 feet. Oil now stands 95 feet from surface. Eight-inch hole cuts Goodridge sand.
2. Chicago well of Oil Company of San Juan; 200 feet deep; 8-inch hole; gas encountered at 100 feet. Touches top of Goodridge sand. Well abandoned because water could not be controlled.
3. Golden Gate No. 7 well of Oil Company of San Juan; 105 feet deep; 8-inch hole; an assessment hole. Oil runs out a little. Cuts Baby sand.
4. Monticello well; 265 feet deep. Oil stands 75 feet from surface. Oil from Goodridge sand..
5. Burlap well of Oil Company of San Juan; 100 feet deep; 8-inch hole. Work on it in progress August 1, 1909.
6. Oil City No. 5 well of San Francisco-San Juan Company; 595 feet deep; 8-inch hole. Cuts Goodridge sand and goes into No. 3 sand. Gas was encountered. Well now full of oil and plugged.

7. Oil City No. 6 well of San Francisco-San Juan Company; 165 feet deep; 8-inch hole. Cuts into top of Baby sand, where oil was struck. "Enough oil to hold claim."

8. Oil City No. 7 well of San Francisco-San Juan Company; 140 feet deep; 8-inch hole. Cuts Baby sand, in which oil was found. "Enough oil to hold claim."

9. Oil City No. 8 well of San Francisco-San Juan Company; 126 feet deep; 8-inch hole. Cuts Baby sand, where small flow of oil was found.

10 Conejos well of San Francisco-San Juan Company; 450 feet deep; 8-inch hole. Cuts Goodridge sand and Baby sand, both of which yield oil. Oily water running from well July 23, 1909.

11. Bryce No. 1 well of Western Investment Company; 165 feet deep; 8-inch hole. Cuts Baby sand, which yields oil. Drilling stopped for repairs. Well sunk in April, 1910, to 500 feet. (A. L. Raplee.)

12. Bryce No. 2 (Oil Johnny No. 1) well of Western Investment Company; 500 feet deep; 8-inch hole. Well sunk in a wash below the horizon of the Goodridge sand. At 200 feet oil was encountered in No. 3 sand. This oil and the rock water was cased off. Oil was again struck in the Mendenhall sand. Oil stands 150 feet from the surface. The well is plugged and shows strong flow of gas when cap is removed. Drilling continued in March, 1910 (A. L. Raplee.)

13. McMoran well; 200 feet deep; 8-inch hole. Cuts Goodridge sand, where oil and some gas was encountered.

14. Bitter Springs No 1 well; 200 feet deep; 8-inch hole. Struck oil in Goodridge sand. Well is plugged.

15. Bitter Springs No. 2 well; 160 feet deep. Drilling stopped on account of repairs to rig.

16. Galloway well of Norwood Company; 1,300 feet deep; 8-inch hole. Strong flow of gas encountered in Goodridge sand. Some oil in this and other sands. No water below 100 feet. Attempt made to reach the Honaker sand was abandoned because of lost tools. Drilling resumed March, 1910. (A. L. Raplee.)

17. Grand Gulch well; 310 feet deep; 8-inch hole. Well begins below Mendenhall sand. Oil encountered in Amber sand. Estimated yield on pumping, 50 barrels a day.

Data regarding the following wells drilled in December, 1909, were kindly supplied by Mr. A. L. Raplee:

18. Red Bed well of A. L. Raplee; 80 feet deep; 8-inch assessment hole. Did not reach oil sands. Struck water.

19. Red Butte well of California Company; 60 feet deep; 8-inch assessment hole. Struck oil in Baby sand.

20. Red Butte well of Monumental Oil Company; 60 feet deep; 8-inch assessment hole. Oil found in Baby sand.

21. Hyde well of Monumental Oil Company; 50 feet deep; 8-inch assessment hole. Oil found in Baby sand.

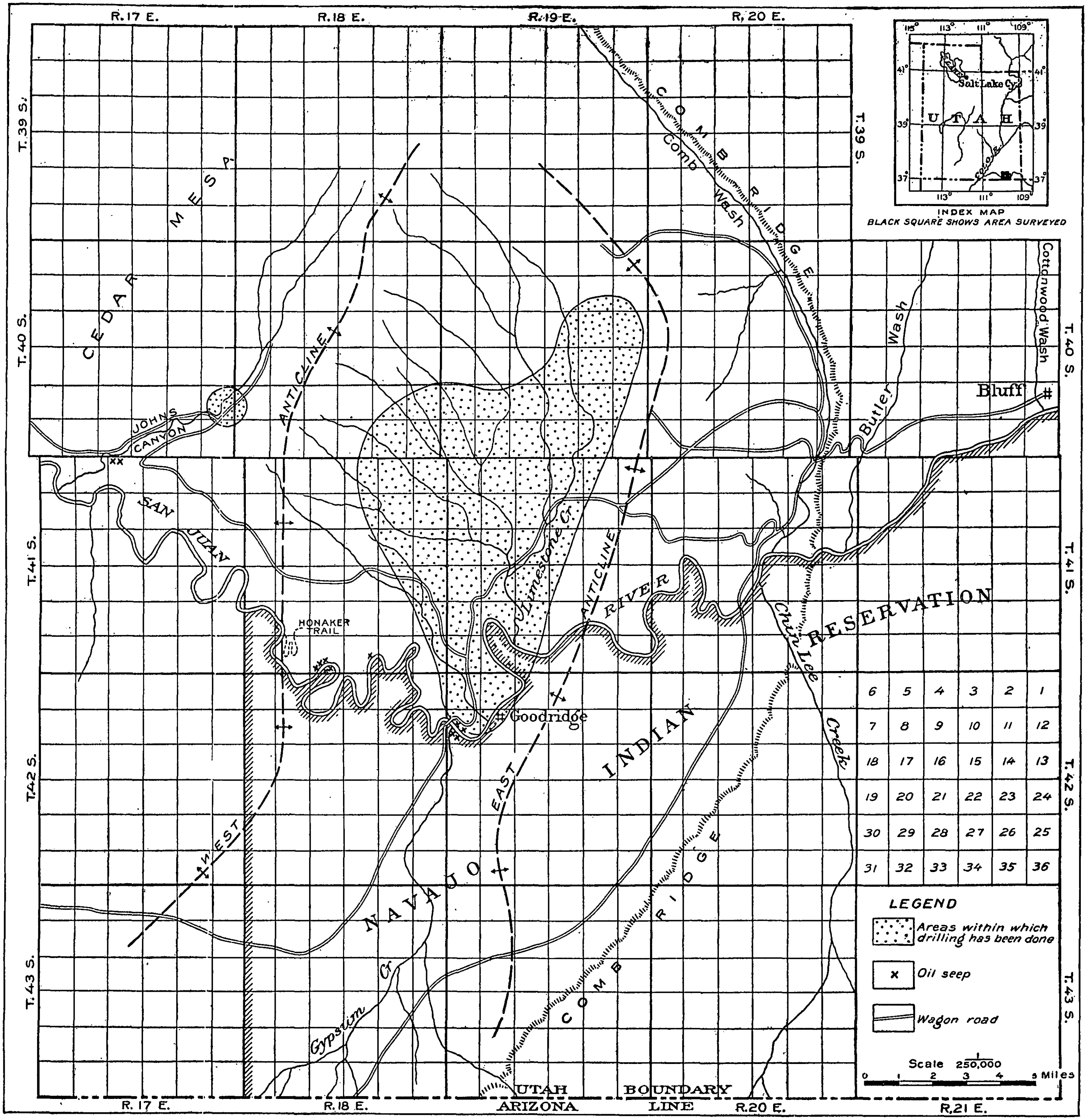
22. Elithia well of Redwood Oil Company of San Francisco; 60 feet deep; 8-inch assessment hole. Encountered oil in Baby sand.

23. McGee & Jackson No. 1 well; 60 feet deep; 8-inch assessment hole. Yields flowing water.

24. McGee & Jackson No. 2 well; 600 feet deep; 8-inch hole. "Struck oil and flowing water." Will be sunk to the Honaker sand.

25. Connecuet well of Connecuet Oil Company of San Francisco; 30 feet deep; 8-inch assessment hole. No water nor oil.

A generalized log of a group of wells starting below the Goodridge sand was furnished by Mr. Raplee and is given here to illustrate the



MAP OF SAN JUAN OIL FIELD, UTAH.

Based on map by E. E. Miller.

arrangement of rock in that part of the field nearest the river. By courtesy of Mr. J. G. Worth the theoretical well section for the entire field as determined by Arthur Lakes is also given.

Generalized well section beginning below Goodridge sand.

	Feet.
Red rock, calcareous shale	200
Blue limestone	10
Fossil limestone	40
Oil sand	20-40
Calcareous shale	56-60
Drab limestone	15
Fossil limestone containing salt water	70
Blue limestone	8-10
Oil sand No. 4	100

Theoretical section.

	Feet.
Red sandstone	100
Drab limestone	10-20
Bleached white sandstone (oil sand No. 1)	50
Pale-red sandstone	200
Drab limestone	20
Bleached sandstone (oil sand No. 2)	40
Red beds	150
Limestone	20
Bleached sandstone (oil sand No. 3)	20
Red beds, including limestone, sandstone, and shale	600
Fossil limestone	200
Bleached sandstone (oil sand No. 4)	80
Sandstone, limestone, etc. (with oil sands 5 and 6)	260

PROSPECTS.

From the data given above it will be seen that 20 of the 25 wells are reported to have struck oil, that oil was encountered in each well wherever the oil sands were penetrated, and that the three lowest sands have not yet been tested by the drill. One of these three, the Honaker, is marked in the canyon wall by a prominent seep. Oil of good quality is undoubtedly present in considerable quantity at each of the seven horizons. A map of the field indicating the existing wells shows that the development has been confined chiefly to the valley of Limestone Creek and that no drilling has been done south of San Juan River. (See Pl. II.) This area was doubtless chosen because wells can be sunk here to the lower oil sands at less expense than elsewhere in the field. But even in this area no well has been sunk deep enough to test the lowest sand. Two wells north of the river, one in the syncline and one on the west anticline, both sunk to the horizon of the Honaker sand or lower, would indicate the possibilities of the field. A test well should also be sunk south of the river at some convenient point between Gypsum Creek and The Monuments. The wells already sunk give valuable information regarding the conditions in the upper oil sands. In making plans for the future it should be noted that the deep-cut canyon of the San Juan may have drained the oil from the field. This consideration, taken in connection with the information afforded by the wells already drilled, indicates that there is little probability of finding gushers or wells of phenomenal yield. It seems reasonable to predict, however, that several wells will be found in this district from which oil may be pumped with profit.

MARKET.

Except for a small supply required for domestic use there is no present demand for oil in southern Utah and northern Arizona, a region which is now and which will probably remain one of the most thinly populated sections of the United States. The oil might be used locally as a means of obtaining power for electrical transmission, but even for this it will probably be found more economical to develop the water power in San Juan River.

Oil from this district would therefore enter the general market to compete with supplies from more favored regions, which it could not do without decreased cost of production and increased transportation facilities. Under present conditions the estimated cost of drilling is $5 a foot, and local owners assume that the Goodridge sand may be reached for an outlay of $2,500 and the Mendenhall sand for $4,500.

Analysis of oil from San Juan County, Utah.

[By David T. Day, U. S. Geological Survey.]

Gravity at 60° F.: Sp. gr., 0.8755; Baumé, 29.9.
Begins to boil at 212° C.
Distillation by Engler's method, by volume:

	Cubic centimeters.	Specific gravity.
150° to 300° C.	29.0	0.8283
Residuum	71.5	.9035
Total	100.5	

Paraffin, 5.77 per cent; asphalt, 3.32 per cent.
Unsaturated hydrocarbons: Crude, 21.2 per cent; at 150°–300°, 6 per cent.

Analysis of oil from Oil City group of wells.

[By Henry R. Ellis, mining engineer and metallurgist for owners.]

[Gravity of crude oil: Sp. gr., 0.837, Baumé, 38°.]

Material.	Temperature.		Per cent.		Gravity.	
	Fahrenheit.	Centigrade.	By volume.	By weight.	Baumé.	Specific gravity.
Naphtha	70° to 250°	21.1° to 121.1°	12.5	11.0	63°	0.731
Light-burning oil	250° to 400°	121.1° to 204.4°	21.2	19.9	51°	.778
Heavy-burning oil	400° to 500°	204.4° to 260°	19.2	19.0	41°	.823
Heavy oils	500° up	260° up	43.0	44.6	33°	.862
Cokings and loss			4.1	5.5		

The following analysis of the oil from Bryce well was made by F. E. Knoch, chemist for the United Oil Company, of Florence. Colo., and furnished by the owner:

Color, dark green; gravity (Baumé), 35.5°; boiling point, 240°.

	Per cent.
Naphtha (=gasoline 12 per cent, volatile matter 3 per cent)	15
Kerosene, 44° Baumé; 110° fire test	35
Mineral seal, 300° fire test	5
Fuel oil	42
Loss	3

The oil contains about 2 per cent paraffin wax and 0.5 per cent asphaltum.

GAS AND OIL PROSPECTS NEAR VALE, OREGON, AND PAYETTE, IDAHO.

By CHESTER W. WASHBURNE.

LOCATION.

The prospects mentioned in this paper are located in southeastern Oregon and western Idaho, near the towns of Vale, Ontario, and Nyssa, in Malheur County, Oreg., and near Payette and Weiser in Idaho. The region described extends along Snake River in a north-south direction for about 30 miles and its western limit lies about 25 miles west of the river. (See Pl. III, p. 48.)

The Payette formation, in which the oil is found, covers a large area in eastern Oregon and southern Idaho. Traces of gas and oil and a few small gas wells are reported from widely separated parts of this area, but in the short time available for the writer's reconnaissance, in October, 1909, it was possible to examine only about 300 square miles of the large area covered by the formation, the survey embracing only the district in which prospecting is now active.

The writer is indebted to most of the oil men of the region for courtesies rendered in the field, especially to A. F. Boyer and T. W. Davidson, who assisted greatly in expediting the writer's work by conducting him to important rock exposures and other places of geologic interest.

TOPOGRAPHY.

The area described is made up of rolling hills that increase in height southward to high mesas and mountains. In this area Snake River and its tributaries, the Malheur, the Weiser, and the Payette, flow in broad alluvial valleys, but the Owyhee flows in a narrow, deep canyon. The most conspicuous landmarks are Double Mountain and Malheur Butte, both composed of igneous intrusives, and Vale, Chalk, and Mitchell buttes, composed of sedimentary rocks. Vale Butte appears to owe its prominence to the induration of conglomerate by silica and lime carbonate deposited by the waters which still escape in the hot springs on the north side of the butte. Mitchell Butte also possibly owes its existence to local induration by hot water. A thin sill of basalt skirts the north base of this butte.

GEOLOGY

The geology of the territory examined is simple. The entire area, except where a few intrusive masses of igneous rock occur, is covered by nearly horizontal lake beds. Surface lavas were not seen but are present farther south in Malheur County, Oreg., and also near Caldwell, Idaho, about 30 miles southeast of Ontario.

STRATIGRAPHY.

The sedimentary rocks of this region are wholly of fresh-water origin—mainly lake deposits with subordinate and local river gravel.

PAYETTE AND IDAHO FORMATIONS.

According to Lindgren [a] the lake beds of this part of the Snake River valley may be divided on paleontologic grounds into a lower or Payette formation (Eocene or Oligocene) and an upper or Idaho formation (Pliocene). The Idaho formation is certainly present at a few isolated localities, where mastodon and *Equus* bones have been found in fluviatile beds that appear to have been deposited after the main features of the present topography had been outlined. On account of the lithologic resemblance of the Idaho and Payette formations it is not always possible to distinguish them in the field.[a] The term Payette formation is therefore rather generally employed in this report to cover the whole indivisible series of Tertiary lacustrine and fluviatile deposits, which includes some areas of the Idaho formation. No other sedimentary rocks are found in this region.

Below the surface, as is shown by the records of the wells, partly consolidated clay predominates markedly over coarser material, but on the surface of the ground sandy and pebbly beds are most conspicuous. Beds of fine conglomerate are common, the pebbles consisting principally of black chert, quartz, quartzite, and rhyolite. No pebbles of basic igneous rock were seen in any of the conglomerate except at Mitchell Butte, where some pebbles of diabase were found. The pebbles are thoroughly waterworn and of nearly uniform size in each bed, usually about one-fourth to one-half inch in diameter, although some beds contain pebbles 2 to 3 inches in diameter. The conglomerate is dark colored, generally from iron stain, and in cliffs it resembles flows of basalt, contrasting conspicuously with the light-yellow sandy clay and sandstone with which it is interbedded. The

[a] Lindgren, Waldemar, Boise folio (No. 45), Nampa folio (No. 103), Silver City folio (No. 104), Geol. Atlas U. S., U. S. Geol. Survey.

conglomerate is crumbly in most places, but locally, as on Vale Butte, it is firmly cemented by silica and calcium carbonate. At a locality 5 miles south of Snake River and 12 miles west of Weiser, Idaho, the pebbles are embedded in sandy red iron oxide, most of which has an oolitic structure.

Most of the fine conglomerate, with well-sorted pebbles less than an inch in diameter, is evenly bedded, and the beds persist for several miles without noticeable change in thickness or coarseness. Thin beds of conglomerate of this type, 15 to 40 feet thick, are well developed on Mitchell and Deer buttes, where their dark color contrasts markedly with the light color of the strata of sandy clay, 50 to 200 feet thick, which separate them. The coarser conglomerate, with pebbles 1 to 3 inches in diameter, is in places cross-bedded; most of the foreset beds dip at angles of 20° to 30° and are capped by nearly horizontal topset beds, in almost ideal simulation of unconformity. Many of the beds of coarse conglomerate are lenticular and do not extend for long distances. They are of different thickness and coarseness and their material is imperfectly assorted.

It is evident that the conglomerate of the latter type is the product of relatively rapid, constricted currents, such as those of confined rivers, which may have flowed over the lake beds at times of temporary desiccation, and that that of the former type—the fine, widespread, even-bedded conglomerate—is the product of broad, relatively slow currents, such as may have prevailed at times along the shifting shore of the ancient Payette lake in which it was deposited. The lacustrine type of sediment is on the whole much more abundant than the fluviatile. The log of the deep well at Ontario and specimens of the strata penetrated indicate that clay composes over 95 per cent of the lower 2,500 feet of the material in the central part of the valley. Sandstone and conglomerate become increasingly abundant upward in the higher beds as well as laterally toward the inclosing mountains, indicating that the shoaling of the lake was marked by the occasional transgression of river deltas and that the source of the sediments was the mountain ranges.

The pebbles in the conglomerate were derived from the neighboring mountain ranges of Oregon and Idaho. The altered chert of the metamorphic limestone in the Blue Mountains furnished most of the pebbles, the quartzite and quartz veins contributing a minor amount. Granite pebbles from the Idaho Range and rhyolite pebbles from the Cedar Mountains are not abundant. Basalt pebbles are absent, except at one locality south of Vale. The pebbles are thoroughly rounded, polished, and well assorted in beds of nearly uniform texture, which, in connection with their small size, indicates that the pebbles in the Vale region were brought from distant sources.

Locally the sandstone and conglomerate are cemented by infiltrated silica or calcite, derived doubtless from the same hot volcanic waters which made the deposits of tufa and which are encountered under pressure in many of the deep wells. The resulting rocks resemble quartzite or impure limestone. Beds of argillaceous limestone, crowded with fresh-water shells, were observed in sec. 2, T. 20 S., R. 44 E. These beds had a faint odor of petroleum. In most parts of the field the rocks contain sufficient carbonate to effervesce with acid.

Beds of white volcanic ash are common. Some of this material is sandy, but much of it is as fine grained as the finest river silt. It appears to be very uniform, as if it had been well assorted before deposition. Under the microscope it is seen to consist of minute angular fragments and irregular plates of amorphous volcanic glass and a few flakes of weathered biotite.

Diatomaceous earth, though reported, is very scarce if not absent in the neighborhood of Vale, Payette, and Weiser, where the writer failed to find it. Russell and Lindgren do not mention the presence of diatoms in their publications on the Payette formation. Probably the abundant fine, white volcanic ash has been mistaken by some observers for diatomaceous earth. However, the writer saw one specimen of true diatomaceous earth, said to have been collected about 50 miles southwest of Vale, and he has seen the earth near Prineville in beds similar to the Payette. It is therefore possible that there is a little diatomaceous earth in the Payette strata.

It will be noted from this description that the Payette and Idaho formations resemble the Truckee formation of Nevada. According to Doctor Dall some of the fresh-water shells are identical with species found in the Truckee beds.

With reference to the occurrence of oil, the stratigraphy is favorable in so far as it indicates the presence of permeable beds of sandstone and conglomerate in a great mass of comparatively impermeable clay and shale. Detailed stratigraphic work in this region will be difficult on account of the general lack of distinct recognizable horizons.

The minimum thickness of the Payette and Idaho formations at Ontario, Oreg., is 4,000 feet, the depth of the Ontario gas well, to which should be added about 200 feet of higher strata exposed in the bluffs northwest of the well. The minimum thickness of these formations is therefore about 4,200 feet; the true thickness may be much greater. This figure places the bottom of the Payette formation below sea level under much of the Snake River valley. At the bottom of the Ontario well the Payette formation is 1,839 feet below sea level, as determined by comparing the depth of the well with a near-by United States Geological Survey bench mark.

As the Payette formation is a fresh-water deposit, apparently laid down on a previously denuded land surface of granite and metamorphic rocks, it is evident that there was considerable depression after the close of the Payette epoch. From previous studies in the Cascade Range of Oregon the writer has concluded that the range probably did not exist as a mountain mass in the Eocene and Oligocene periods and that the drainage of eastern Oregon and Idaho was then directly westward to a shore line that is now buried beneath the lavas of the Cascade Range. The passes through the range in the Columbia gorge and through the Blue Mountains in Snake River canyon, immediately north of the Vale region, are both to be considered the results of post-Miocene erosion.

The physiographic considerations just stated indicate that the Payette formation is of late Eocene or Oligocene age. The climatologic evidence furnished by the Payette sediments also harmonizes best with early Tertiary conditions in eastern Oregon. From imperfect paleontologic evidence the same conclusion has been recorded by Lindgren in the later[a] but not in the earlier[b] folios on this region.

Fresh-water shells, most of them chalcedonized, and fish bones are locally abundant, but the writer's collections were not good enough for reliable determinations. Collections made in sec. 12, T. 20 S., R. 45 E., and in sec. 29, T. 19 S., R. 44 E., were examined by W. H. Dall, of the Geological Survey, and J. W. Gidley, of the National Museum, who report that the species are probably Miocene or later. One *Carinifex* appears to be a species common in the Truckee formation of Nevada, which is lithologically similar to the Payette and Idaho formations. The Idaho formation is of Pliocene age. Some shells collected at a much lower horizon 12 or 13 miles west of Weiser, Idaho, are doubtfully referred by Doctor Dall to the lower Eocene.

STRUCTURE.

The geologic structure of the region is not pronounced; there are no sharp folds nor large faults. In general, the Snake River valley is a shallow syncline, with only minor irregularities.

FAULTS.

The observed faults include a few small displacements that trend northwest and southeast. The absence of large faults is surprising, as the region is physiographically a part of the high plateau of southeastern Oregon and northwestern Nevada, whose great fault blocks have been described by Russell.[c]

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[a] Lindgren, Waldemar, Nampa folio (No. 103), Silver City folio (No. 104), Geol. Atlas U. S., U. S. Geol. Survey. For paleobotanic arguments see Knowlton, F. H., Bull. U. S. Geol. Survey No. 204.

[b] Lindgren, Waldemar, Boise folio (No. 45).

[c] Russell, I. C., A geological reconnaissance of southeastern Oregon: Fourth Ann. Rept. U. S. Geol. Survey, 1884, pp. 431-464; Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: Mon. U. S. Geol. Survey, vol. 11, 1885.

Three small faults cut the bluffs on the northwest side of Sand Hollow in secs. 29 and 30, T. 19 S., R. 44 E. One of these trends N. 40° W., dips 70° NE., and is downthrown 5 feet on the northeast; another, one-fourth mile to the southwest, trends N. 60° W., dips 80° NE., and is downthrown 20 feet northeast; another fault, about 100 yards southeast of the last, is not well exposed, but it probably has a downthrow of about 50 feet on the southwest side. A small fault cuts the top of a spur on the north side of Cow Hollow, in the SW. ¼ sec. 4, T. 20 S., R. 45 E. It trends in a general northwest-southeast direction, and a ledge of brown fine conglomerate is depressed about 75 feet on its northeast side. In the northeast corner of sec. 7, T. 19 S., R. 45 E., there are indications of a similar fault, which, according to information from Mr. R. W. Eames, probably extends southeastward through secs. 8 and 17. Two small faults, trending nearly east and west, were seen near the east quarter corner of sec. 6, T. 20 S., R. 44 E. Many other small faults were doubtless overlooked in the reconnaissance.

FOLDS.

Snake River valley near Payette is a syncline, which terminates abruptly on the east against the granite mountains of Idaho and which extends westward across the northeast corner of the Mitchell Butte quadrangle (Tps. 19 and 20 S., Rs. 45 and 46 E.) to an anticline whose axis is marked by Double Mountain. The Snake River syncline and the Double Mountain anticline are the two major structural features of the region examined.

The Snake River syncline is an almost imperceptible broad downwarp or basin of the Payette formation. It is not yet known whether the Idaho formation is involved in this fold or was merely deposited in a valley eroded in the Payette beds, but the Pliocene fossils reported from many parts of the valley indicate the presence of the Idaho formation. On the east side of the basin, in the Boise quadrangle,[a] dips as high as 12° W. are reported near the granite mountains, but in general the dips are between 3° and 5° W., except north of Weiser, where an igneous intrusion has uplifted the strata for a short distance.

On the west side of the valley the dips are from 2° to 6° E., decreasing toward Snake River. South of Huntington, Oreg., the general strike appears to be northeast, but it swings nearly due north in the hills west of Weiser, and to the northwest in the Vale region.

In the north half of the Mitchell Butte quadrangle these eastward dips are interrupted by the Double Mountain anticline, west of which, at Willow Spring, the dip is as high as 15° W., but farther from the mountain the dip rapidly decreases to 3° to 5° W. The

[a] Lindgren, Waldemar, Boise folio (No. 45), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

north end of the Double Mountain anticline appears to die out in Sand Hollow, where there is barely a suggestion of a low arch in the rocks. Double Mountain is itself an intrusive mass of igneous rock, but the sill of basalt east of it is folded with the inclosing Payette strata and it is uncertain whether the anticline was produced by the intrusive force of the lava or whether the intrusion followed or determined the axis of a fold that resulted from compression.

Minor folds in the low-dipping rocks can be detected with considerable difficulty and some uncertainty. Opposing dips suggest a minor fold near the center of sec. 19, T. 19 S., R. 44 E. The trend of this fold is northwest; its structural height is about 150 feet; and its breadth about a mile. A similar low arch is indicated by the dips in the hills on both sides of a small creek near the center of sec. 23 of the same township. Another is indicated at the east end of Deer Mountain, in sec. 11, T. 21 S., R. 45 E. (unsurveyed). There appears to be a small imperfect dome near the southwest corner of sec. 4, T. 19 S., R. 45 E., near well No. 1 of the Baker and Malheur Oil Company. Mr. R. W. Eames, geologist of the Mammoth Oil and Gas Company, believes that there is a similar dome in sec. 6, T. 20 S., R. 45 E.

The dips east of Weiser, Idaho, suggest a low anticline at the mouth of the canyon of Monroe Creek, about 1 mile northeast of the city. The detailed structure near the successful gas wells in Ontario and Payette is unknown because of the alluvial covering, but the wells are near the general structural center of the broad Snake River syncline.

IGNEOUS ROCKS.

The only igneous rocks seen in the region examined are clearly intrusive in the Payette formation and consist of basalt, rhyolite, and possibly hypersthene andesite.

It has formerly been assumed that the high hills north of Weiser were composed of lavas older than the Payette formation and that they formed the north shore of the ancient Payette lake, but an examination of the walls of the canyon where Snake River cuts through the range of hills reveals the fact that the range is composed of several intrusions of basic igneous rock which have pierced the Payette strata. The Payette formation continues north of the range, and possibly enters the valley of Burnt River, Oregon, where similar rocks were seen. This range decreases in height southwestward, and the writer is informed that it may be followed more than 25 miles in that direction, to the neighborhood of Westfall. Cottonwood Mountain also, not far from Westfall, is said to be composed of igneous rocks, but it was not visited by the writer.

Malheur Butte, west of Ontario, is a volcanic neck of basalt whose intrusion has sharply upturned the rocks on the east, north, and west sides, and presumably also on the south side, where the strata are concealed by alluvium. On the east side of the butte a bed of fine conglomerate dips away from the basalt at an angle of 45° NE. The conglomerate is broken by an intricate network of minute faults. In soft lake beds one-half mile northeast of the butte the dip is 15° NE.; and in the same rocks one-half mile north of the butte the dip is 15° N. Beyond this distance the strata are not affected by the intrusion. Except for the absence of oil seeps this volcanic uplift is identical with the Cerro La Pez of the Ebano field and other similar volcanic necks in Mexico, around which oil fields have been developed. However, the absence of seeps at Malheur Butte makes it an uninviting place to well drillers. Certainly no well should be drilled within 100 yards of the butte, on account of the possibility of encountering the hard basalt.

Double Mountain is an intrusive mass of basalt with considerable rhyolite in its northern part. A separate small intrusive plug of rhyolite makes a conical hill near the west quarter corner of sec. 8, T. 20 S., R. 44 E. One-half mile southwest of this rhyolite plug there is a large dike of basalt which runs 2 miles northwest from Double Mountain to Willow Spring. On the opposite or east side of the mountain the basalt appears to be interbedded in places with the Payette strata, but probably as intrusive sills, not as contemporary flows. One of these interbedded sheets of basalt, in sec. 34, T. 20 S., R. 45 E., was examined and found to have smooth chilled surfaces at both top and bottom. From Rock Spring Canyon, in T. 21 S., the outcrop of the sill winds along the irregular front of the hills northward to Chalk Butte, where it disappears.

HOT SPRINGS.

The numerous hot springs in the region are generally thought to be connected with underlying hot lavas. Certain features of chemical composition and geologic distribution, however, make it probable that many of the hot springs of Oregon are not merely meteoric waters which have been heated by contact with lava, but are waters which have risen from great depths or have escaped from ascending magmas. The high temperature of the hot spring at Vale—198½° Fahrenheit—and of several other remarkably hot springs indicates that the water has not had a long passage through cold rocks.

Hot springs occur at five or more localities in the Mitchell Butte quadrangle—(1) at Vale; (2) on Malheur River 15 miles above Vale; (3) on the south side of Mitchell Butte; (4) on the east side of Deer Butte, in Owyhee Canyon; (5) about 15 miles above Deer Butte, in the same canyon. In the surrounding region there are several hundred hot springs, a few of which have been described by Russell[a] and others.

[a] Russell, I. C., Bull. U. S. Geol. Survey No. 199; also Water-Supply Paper 78.

In this paper the main interest in hot springs lies in their possible connection with the origin of the natural gas found in the wells. Becker[a] says: "Great numbers of hot springs in France, Germany, Austria, and elsewhere carry methane." R. T. Chamberlin[b] and others have found that marsh gas (methane) is present in most gaseous inclusions of igneous rocks, including granitic quartz, augite, etc. Many investigators[c] have detected methane in the emanations of volcanoes. The discovery of methane in the hot springs would afford a possible explanation of the origin of the gas, and the hot spring at Vale was therefore tested for methane as carefully as the means at hand would permit. On account of the explosive ebullition of the scalding water of the main spring it was necessary to work at a neighboring small, quiet, somewhat cooler pool on the bank of the river. A vessel filled with cold water was inverted in the pool until it became filled with gas. After much difficulty, due probably to the presence of water vapor and other gases in the collecting vessel, a weak explosion was obtained, proving the presence of a combustible gas, but whether this gas was methane or sulphureted hydrogen was not determined.

The water contains hydrogen sulphide, which is indicated by odor and by testing for sulphide with a silver coin. Moreover, in stirring the rocks at the bottom of the pool a few bits of oil or grease were loosened, which appeared as small iridescent patches on the top of the water. The latter observation is of doubtful value, because farmers use the pool for dipping the carcasses of hogs, and it is barely possible that the iridescent films were due only to hog grease.

The writer had no opportunity to examine other hot springs. Mr. R. W. Eames reports inflammable gas in a hot spring near the Hoffman ranch, 7 miles west-southwest of Owyhee post-office; also at the Neal hot spring in sec. 9, T. 18 S., R. 23 E. It is said that Mr. O'Toole, of Weiser, found inflammable gas in a hot spring in the bed of a creek 6 miles northeast of Weiser. These reports were not verified.

Deposits of tufa and other traces of extinct hot springs are more abundant than the active springs. On the margin of a small dike running north from the volcanic neck called Malheur Butte there is a semicircular area of siliceous sinter and hornstone, evidently deposited by hot water. The two Vale buttes are composed of the same kind of rock as the surrounding region, but it has been indurated by the deposition of lime carbonate and silica between the grains. The induration took place about narrow channels resembling ore shoots, and the results of erosion are two conspicuous hills, which several travelers have mistaken for volcanic necks. The

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[a] Becker, G. F., Relation between local magnetic disturbances and the genesis of petroleum: Bull. U. S. Geol. Survey No. 401, 1909, p. 12.

[b] The gases in rocks, Carnegie Institution of Washington, 1908.

[c] See analyses and references quoted by F. C. Lincoln in Econ. Geology, vol. 2, 1907, p. 258.

deposition of silica and carbonate is most marked in the sandstone and conglomerate, which in places are converted into hard, flinty rocks. The shale, on the other hand, appears to have been decomposed into structureless clay and to have assumed bright colors—white, red, or green—as shown by the road excavations at the west end of the butte. Several deposits of tufa occur on the hills. The process of deposition is still going on in the pipe through which the hot spring discharges, which requires frequent cleaning. Mitchell Butte likewise probably owes its prominence to the local induration of layers of conglomerate. On the upper part of the creek which flows through Cow Gulch along the eastern margin of T. 20 S., R. 44 E., there are said to be several deposits of calcareous tufa, many of which have the form of gigantic mushrooms.

Perhaps the most interesting tufa deposit in the field is a conical hill on the northeast side of Mud Spring, in sec. 29, T. 20 S., R. 45 E. This hill has the form, structure, composition, and general appearance of a geyser cone of the Yellowstone Park. No water, hot nor cold, now issues from the cone, but on its southwest margin is a large cold spring called Mud Spring, from which an odorless inflammable gas escapes copiously. It is highly probable that the water and gas have followed the underground channel of the old geyser for a considerable distance, but there is no certain indication whether the gas comes from considerable depths within the earth or is gathered by the water on its way to the geyser channel. The water is probably not of deep-seated origin, because it is cold (62° F.) and drinkable, having only a slightly salty taste.

The opinion has been expressed that in this region hot water rises under high pressure through fissures but in places turns aside from its path to the surface and saturates the porous beds of sand. This opinion, expressed by Russell and by Lindgren, is supported by many observations made in the neighborhood of Vale, where the temperature of the water encountered is far above the temperature which a normal heat gradient would give at the same depth. Several wells have encountered deep, comparatively cold meteoric water after passing through higher strata containing very hot water. It seems likely either that the lower porous bed reached by such wells is not a continuous sheet and is not cut by fissures carrying hot water, or else that the deeper walls of the fissures have been made impervious by cementation, so that they resemble the indurated rocks of the Vale buttes. A well showing this is the Hirsch artesian well, drilled near a hot spring by Hope Brothers & Eastman in Dry Gulch (sec. 4, T. 16 S., R. 43 E.), 18 miles north of Vale. This well struck a flow of moderately warm water at 1,700 feet. It is reported that the well contains a little gas. In the county well drilled near the court-house at Vale hot water was encountered at

600 feet and cool sulphur water at 1,000 feet. Also a trace of oil is reported in shale at 1,100 feet.

SALT AND SULPHUR.

Salt is reported from well No. 3, Baker and Malheur Oil Company, in sec. 29, T. 19 S., R. 45 E. Only a few small pieces were obtained and the depth from which they came is not known. It is said that Mr. Anthony struck some very salty water at a depth of 40 feet in a 60-foot prospect well in sec. 6, T. 20 S., R. 44 E. Fragments of rock salt were also obtained from the Mammoth well. Crystals of native sulphur were found in the drillings of the Columbia well.

GAS AND OIL.

INDICATIONS OF OIL.

Reports indicate that traces of oil are widely scattered over southeastern Oregon and the Snake River plains of Idaho. The writer was unable to visit many of the places designated, but he has personally noted traces of oil at four places and of gas at many places. The localities visited are enumerated below.

VERIFIED INDICATIONS OF OIL.

A dark-gray band of hard, petroliferous sandstone runs along the face of a low cliff on the west bank of Sand Hollow, in sec. 29, T. 19 S., R. 44 E., 10 miles southwest of Vale. The sandstone is conspicuous on account of its color contrast with the yellow sandstone and shale that inclose it. It contains many bivalves and gastropods, all fresh-water species. The rock has a strong odor of petroleum, especially near some faults that cut across the cliff. Samples tested in Vale with chloroform yielded a few drops of light, almost colorless oil. The writer crushed other samples and tested them in the chemical laboratory of the University of Oregon by extraction with ether. The result was a few drops of somewhat more viscous amber-colored oil, in quantity too small for analysis, but in general appearance resembling paraffin oil rather than asphaltic oil.

A sandstone similar to the last occurs in the NW. ¼ sec. 2, T. 20 S., R. 44 E., on the east side of a small creek. This rock also has a decided odor of petroleum. At well No. 1 of the Eastern Oregon Oil Company (see p. 44) and at well No. 1 of the Columbia Oil and Gas Development Company (p. 43) small traces of oil were observed.

REPORTED INDICATIONS OF OIL.

Similar traces of oil are reported from the gas horizons of several of the other prospect wells, as shown by the logs. (See pp. 41–46.) Many of these reports are probably correct, but the writer was unable to verify them, for all the traces reported are said to have been too small to afford samples. It is reported that a sample amounting to about 1 quart was recently obtained from the Eastern Oregon well. Most of the companies operating in this field have not been promoted by itinerant oil boomers for the purpose of selling stock but have been established by local business men, who are investing their own money and whose statements therefore deserve more confidence than can be placed in the reports of oil boomers.

Traces of oil are reported from two water wells drilled in Vale. One of these is the county well, at the court-house, which encountered strongly sulphurous water in shale at 1,000 feet and a trace of oil at 1,100 feet. A similar indication is reported from the Boswell & Johnson well, which encountered at 300 feet weak sulphur water on which films of oil were observed. These reports are substantiated by several citizens of Vale.

The writer saw a small sample of light-greenish oil, about 1 ounce, said to have been collected from water encountered in sand at 200 feet in a 250-foot well on the Hoffman ranch, on Owyhee River, 7 miles above Owyhee post-office. The water is said to be accompanied by a small amount of inflammable gas.

INDICATIONS OF GAS.

Indications of gas are much more numerous and more widely distributed than the signs of oil, and gas has been obtained in quantities sufficiently large to indicate that it may be of commercial importance. Four wells in the Payette formation have struck gas under sufficient pressure to throw water and mud over the tops of the derricks, which are about 80 feet high. These wells are the Ontario Cooperative Gas and Oil Company's well in Ontario, Oreg. (p. 40); the Oregon Oil and Gas Company's well at Payette, Idaho (p. 40); a well 1,050 feet deep mentioned by Robert N. Bell,[a] state inspector of mines for Idaho, who writes that it was located "a short distance above Weiser, on the Oregon side of Snake River, several miles northwest of Payette;" and the Leake well, near Burns, Oreg. (p. 56).

VERIFIED INDICATIONS OF GAS.

As described on another page, the writer has personally verified the occurrence of a good flow of gas from the Ontario Company's well, and photographs of their eruptions leave no doubt that the well at Payette and the Leake well near Burns were both big gas wells when first struck. Although a wooden plug was driven into the pipe of the Payette well, considerable gas still escapes.

[a] Ninth Ann. Rept. Mining Industry of Idaho, for 1907, p. 84.

At the residence of A. F. Boyer, in Ontario, gas is obtained from a 3-inch well, 215 feet deep, in quantity sufficient to maintain 12 jets in the house and supply the cooking range. This well was drilled in September, 1902, and the flow of gas is believed to have increased since that time. The gas in this well, as in many others, is mixed with water, which rises within 6 feet of the surface and from which the gas is separated by allowing the water to flow through a 25-barrel tank.

It is said that about 40 water wells in Ontario contain some gas. The writer visited two of these, one a deep well near the sidewalk on the main street, the other a shallow well at a private residence 2 blocks farther west. At the former a large blue flame could be obtained when the well was being pumped; at the latter there is only a trace of gas. More or less gas is found in most of the deep wells. (See descriptions of wells, pp. 40–46.)

REPORTED INDICATIONS OF GAS.

There can be little doubt of the widespread occurrence of gas in small amounts in a territory about 200 miles wide in the Snake River valley and the adjoining parts of southeastern Oregon. The writer was not able to visit all the places where it is said to occur, and some errors may appear in the following list of localities, but most of the reports were substantiated by many residents of the district.

It is reported that an artesian well sunk at the Ontario Hotel struck some gas at 1,050 feet.

Gas was struck in a water sand 250 feet deep at Schreiber's ranch, near Nyssa. The quantity is said to be sufficient to run an engine which pumps the well.

Gas is reported at 100 feet in a well drilled by Mr. Jensen near Mud Spring, in sec. 29, T. 20 S., R. 45 E. The gas in this spring has been described on p. 31.

On Owyhee River, 21 miles south of Ontario, Mr. Skinner obtained gas in two shallow water wells.

In an artesian well at Mosquito, Oreg., 11 miles north of Ontario, a good flow of gas is reported from a depth of 1,400 feet.

Gas is reported in an artesian well on the Hirsch ranch, in Dry Gulch, 18 miles north of Vale. The depth of this well is 1,700 feet.

Gas was struck at 900 feet in cold water in a well at T. W. Halledy's house in Vale. Some marsh gas is also present in the sulphur water of B. W. Mulkey's well in Vale.

It is said that nearly all the deeper wells near Westfall, about 20 miles west of Vale, contain more or less gas; and the same statement is made concerning several wells between Westfall and the Harney Valley field, which is 75 miles southwest of Westfall.

Gas has recently been struck with hot artesian water at a depth of 900 feet near Mountain Home, Idaho, in a well drilled by the Oregon Railroad and Navigation Company at Hammett station, in Medbury Valley. When the water is allowed to flow the gas may be ignited, burning with a flame about 2 feet high. This locality is about 75 miles southeast of Ontario.

MUD VOLCANOES.

According to Robert N. Bell, Idaho inspector of mines:[a]

> Gas springs and gaseous emanations from shallow wells are very numerous in the vicinity of Payette and Ontario, and in the whole sedimentary area of the Payette Valley, where many mud springs also occur. Strong flows of gas have been encountered as far up as the east side of Squaw Butte near Sweet, Idaho, wherever wells have been sunk. Numerous low, dome-shaped hillocks in the circular basin back of the Marsh and Ironton ranch are probably due to mud springs that have choked up and dried out into their present form. Similar manifestations, including open mud springs, occur at several places farther down the Payette Valley, along the bottom lands.

The description indicates that these dome-shaped hillocks should be classed with mud volcanoes of a type described by Hoefer,[b] in the Baku oil fields of Russia. Hoefer notes the association of mud volcanoes of this type with oil regions, but he describes them as produced by the ebullition of gas, so their true association should be with gas rather than oil. The Salt Lake gas field is characterized by numbers of such gas springs, according to Boutwell,[c] who says that the mounds have circular pits about 25 feet in diameter at their apices. The pits are occupied by actively bubbling springs of cold water.

The writer visited a low mound of mud in sec. 3, T. 20 S., R. 44 E., about 1½ miles east of the Columbia company's well. At the time of the visit there was no crater nor was any gas escaping from the mound. Recent rains had evidently eroded the mound considerably, leaving but 2 or 3 feet of mud projecting above its rock base of Payette strata. Residents claim that the mound had grown over 4 feet during the preceding year and that gas escaped at times from its summit. It is quite possible that this mound should be classed among the mud volcanoes.

Mud Spring, in sec. 29, T. 20 S., R. 45 E., described on page 35, would probably have the form of a mud volcano if it did not occur on a hillside and if the volume of water it discharges were not so great as to rapidly erode its lower margin. This spring, which is banked with mud on all sides except the outlet, occupies a circular basin about 15 feet across at the water surface. The ebullition of gas from the spring is constant and at times is extremely vigorous.

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[a] Ninth Ann. Rept. Mining Industry of Idaho, for 1907, p. 86.

[b] Das Erdöl, vol. 2, ed. of 1909, Chapter on Schlammvulkane und Salsen.

[c] Boutwell, J. M., Bull. U. S. Geol. Survey No. 260, 1905, pp. 468–479.

WELLS AND PROSPECTS.

Prospecting for oil and gas in Malheur County has been intermittently active for about five years, but most of the important work has been done during the last three years. Seven companies were operating in October, 1909. At that time there were fifteen wells in the field, including six wells drilled primarily for artesian water, having the depths of 3,596, 1,700, 1,506, 1,400, 1,140, 1,100, 1,050, 1,050, 900, 850, 740, 340, 335, 320, and 163 feet. Drilling was progressing on seven wells near Vale and on well No. 2 of the Oregon Oil and Gas Company in Payette.

ONTARIO COOPERATIVE GAS AND OIL COMPANY.

The deepest boring in the field is the gas well of the Ontario Cooperative Gas and Oil Company, of Ontario, Oreg. This well (No. 1, Pl. III), which is in Ontario, near the residence of A. F. Boyer, is 3,650 feet deep, and its surface elevation is 2,159 feet, the bottom of the well being therefore 1,489 feet below sea level, yet it did not reach the base of the Payette formation. A small amount of gas was encountered at 640 feet, and at 986 feet a stronger flow of gas blew the water out of the well. At 1,070 feet, when the hole contained 1,000 feet of water giving a resistance of over 440 pounds per square inch, gas was struck which blew water and mud over the top of the derrick. This operation was repeated at 2,204 feet, when the hole contained about 2,000 feet of water giving a resistance of over 880 pounds per square inch. These depths were all measured from the derrick floor, about 4 feet above the ground surface. Instrumental measurement of the gas pressure, made somewhat later, gave 420 pounds per square inch. At the time of the writer's visit, in October, 1909, the well was capped, and on opening the cocks the accumulated gas escaped with a roar which indicated high pressure but which decreased noticeably in about half an hour. No means were at hand for measuring the pressure and no attempt has been made to determine the amount of gas which the well will deliver. It is probable, however, that if the well were cleaned and if the casing were cut at the higher gas horizons a very good flow might be obtained. The gas has an odor resembling gasoline and burns with an almost colorless flame.

The well was drilled with cable tools to 2,200 feet and deepened with the rotary to 3,587 feet, when the cable tools were replaced. At 3,587 feet it was probably the deepest rotary boring in the United States, but in Mexico two deeper wells have been drilled by the rotary method. On account of the better samples of the rock which are furnished by cable tools the following log of the well is more reliable in detail above 2,200 feet than at greater depths, but there is no doubt that the samples from the lower part of the well are all typical of the Payette formation.

Log of well No. 1 of Ontario Cooperative Gas and Oil Company at Ontario, Oreg.

Character of rock.	Thickness.	Depth.[a]
	Feet.	*Feet.*
Soil, black, sandy	8	0
Sand and coarse gravel with water	16	8
Clay, blue, soft	67	24
Sand with much water	10	91
Shale, sandy	53½	101
Hard "shell"	½	154½
Shale, blue	481	155
Gas		636
Shale, blue	70	636
Shale with some gas	5	706
Shale, blue	125	711
Hard "shell"	1	836
Shale with trace of oil	9	837
Shale, blue	32	846
Hard "shell"	2	878
Shale	88	880
Sand with gas under high pressure	14	968
Shale	4	982
Sand	7	986
Shale	65	993
Sand with gas under very high pressure	8	1,058
Shale	132	1,066
Hard "shell"	1	1,198
Shale	20	1,199
Hard "shell"	1	1,219
Shale	3	1,220
Hard "shell"	3	1,223
Shale	78	1,226
Hard "shell"	1	1,304
Shale and sand	291	1,305
Shale, brown	80	1,596
Shale, sandy	20	1,676
Shale, blue	85	1,696
Hard "shell"	5	1,781
Shale, brown	110	1,786
Shale with a little gas	100	1,896
Shale, blue	150	1,996
Shale, blue, with gravel	10	2,146
Shale, sandy	43	2,156
Sand with trace of oil and much gas under high pressure	1	2,199
Shale, soft	276	2,200
Shale, hard	30	2,476
Shale, blue	165	2,506
Shale, blue, mixed with small pebbles of black chert	165	2,671
Shale, hard, brittle	50	2,836
Shale, soft, blue	120	2,886
Shale, hard	20	3,006
Shale, dark	80	3,026
Shale, blue	225	3,106
Shale, dark, hard	70	3,331
Shale, blue	65	3,401
Shale, dark, hard	41	3,466
Shale, dark, blue	60	3,507
Shale, dark, hard	29	3,567
Shale, blue	54	3,596
Total depth of well[b]		3,650

[a] In the logs in this paper the depths given refer to the top of each stratum measured in feet from the surface of the ground.

[b] In September, 1910, the depth of the Ontario well is reported to be 4,000 feet. Samples submitted from this depth are identical in character with the light-blue shale found at higher horizons, and there can be no doubt that the well has not yet passed entirely through the Payette formation.

OREGON OIL AND GAS COMPANY.

In Payette, Idaho, a well of small diameter (No. 2, Pl. III), drilled by the Oregon Oil and Gas Company, struck a "blow out" of gas on October 18, 1907.[a] The depth of the gas sand was 740 feet, and the

[a] A full description of this well, including a photograph of its eruption, will be found in the Ninth Annual Report of the Mining Industry of Idaho for the year 1907, by Robert N. Bell, state inspector of mines; pp. 79-92, from which this description is abstracted.

pressure was sufficient to blow a column of water, sand, and shale to a height of 150 feet. The well was drilled through an almost continuous body of smooth, blue-gray shale, with occasional thin layers of sandy material containing smaller flows of gas. This small hole became clogged with sand and gravel and was finally plugged. A new well of larger diameter has been started near by for the purpose of trying to get through the gas stratum, in order to obtain oil at lower depths. As this gas occurs at a comparatively shallow depth it would seem wise to develop it for local lighting or other use rather than to case it off and expend a large sum of money in the much more uncertain quest for deep oil.

MALHEUR OIL COMPANY.

The Malheur Oil Company, of Union, Oreg., is drilling a well in sec 31, T. 19 S., R. 44 E., 10 miles southwest of Vale (No. 1, Pl. III). At the time of the writer's visit the well was 1,500 feet deep, as shown by the log, and a small amount of gas was issuing with a strong odor of hydrogen sulphide. Igneous rocks were encountered at several depths in this well, the samples, as determined by a pocket lens, being apparently of two types, one a diabase with augite and lath-shaped plagioclase, the other a basalt or basic andesite containing augite and possibly hypersthene in a stony groundmass. The former rock was much decomposed and contained crystals and veins of calcite. The log of the well indicates an unusual amount of igneous rock.

Log of well No. 1 of Malheur Oil Company, in sec. 31, T. 19 S., R. 44 E.

Character of rock.	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow	40	0
Clay, blue	45	40
Sand, dry	30	85
Shale, black	7	115
Sand, trace of oil and gas	8	122
Shale, white	8	130
Clay, blue	2	138
Sand with traces of oil	140	140
Clay, blue	12	280
Sand with traces of oil	22	292
Clay, brown	5	314
Shale, gray	6	319
Conglomerate with artesian water	75	325
Basalt	5	400
Clay, red	40	405
Basalt	8	445
Clay, red	42	453
Conglomerate	12	495
Conglomerate, red	88	507
Clay, variegated colors; firm, soapy	92	595
Shale, blue	15	687
Basalt, vesicular	33	702
Clay, chocolate and red colors	6	735
Shale, blue	9	741
Basalt, very hard	10	750
Conglomerate, soft	7	760
Limestone	½	767
Bowlders of igneous rock and clay	133½	767½
Basalt, very hard	45	901
Clay, dark brown	5	946
Shale, light colored	85	951

Log of well No. 1 of Malheur Oil Company, in sec. 31, T. 19 S., R. 44 E.—Continued.

Character of rock.	Thickness.	Depth.
	Feet.	*Feet.*
Conglomerate, fine	2	1,036
Sand, gray; fragments of bones; trace of oil	13	1,038
Sand, coarse	6	1,051
Shale, blue	4	1,057
Diabase lava, partly decomposed; locally miscalled "dolomite"	200	1,061
Shale, white; probably volcanic ash	50	1,261
Shale, tough, blue, with show of oil	50	1,311
Shale, white, gritty; probably volcanic ash	145	1,361
Total depth October 8, 1909		1,506

Samples of the red, green, and chocolate clays appear to be altered igneous rock and shale, similar to the clays seen near the hot springs. The bowlders and clay passed through between 767½ and 901 feet represent a decomposed igneous sill or flow.

COLUMBIA OIL AND GAS DEVELOPING COMPANY.

The Columbia Oil and Gas Developing Company, of Spokane, Wash., is drilling in the SW. ¼ sec. 4, T. 20 S., R. 44 E. (No. 2, Pl. III), less than a mile north of the nearest outcrop of igneous rock on the north end of Double Mountain, the effect of which is seen in the basalt encountered in the well. At the time of the writer's visit, in October, 1909, the log of the well was not available and the following information was kindly furnished by the drillers. The well was about 850 feet deep at that time and had passed through the usual beds of clay, sand, and fine conglomerate, including beds of sandy shell limestone between 645 and 780 feet, similar to that encountered in the Mammoth well at about 1,200 feet. From 500 to 580 feet the rock was very hard basalt with a little gas, presumably in fissures, and at the bottom of the basalt a strong flow of gas was encountered, which blew the water and sand 3 to 5 feet above the derrick floor. This gas, which has a strong odor of hydrogen sulphide, has since weakened in pressure and does not now flow in quantity sufficient for commercial use. Some small pieces of native sulphur were found among the samples from this well and are thought to come from the gas horizon at 580 feet. The writer observed that drops of oil, most of them containing much gas, rose to the surface of the bailing water of this well and spread in iridescent films, as described more fully on page 47.

MAMMOTH OIL AND GAS COMPANY.

The Mammoth Oil and Gas Company, of Union, Oreg., is drilling in Cow Hollow, in sec. 6, T. 20 S., R. 45 E., 9 miles south of Vale (No. 3, Pl. III). Traces of oil and gas are reported from several depths, as shown in the following log. The gas smells strongly of hydrogen sulphide. A water well 210 feet deep furnishes a good supply of excellent water.

Log of well No. 1 of Mammoth Oil and Gas Company, in sec. 6, T. 20 S., R. 45 E.

Character of rock.	Thickness.	Depth.
	Feet.	*Feet.*
Soil	8	0
Sandstone	8	8
Sand, light gray	4	16
Shale, gray, hard at base	14	20
Sandstone, dark gray	24	34
Sand, gray; trace of oil and gas	15	58
Clay, blue, tough, sticky	70	73
Gravel, coarse, pebbles one-half inch to 2 inches in diameter	9	143
Gravel, fine, and clay, with gas	9	152
Shale, blue	22	161
Gravel, fine, with water which rose 30 feet in well	10	183
Clay, compact, tough, blue, hard layer at base	121	193
Shale, light gray	12	314
Shale, in alternating hard and soft layers	40	326
Sandstone, marly, fossiliferous	5	366
Shale, light gray	12	371
Sandstone, gray, hard, fine grained	14	383
Shale, dark, laminated	10	397
Sandstone, with fossil *Unio*	4	407
Clay, gray	20	411
Sand, fine grained, with water	6	431
Gravel and clay	24	437
Shale, hard, dry, gray	30	461
Clay, blue, tough	10	491
Sand, with water	12	501
Shale, light blue	12	513
Clay, dark blue, tough ("gumbo")	8	525
Clay, blue	10	533
Sand, with gravel; trace of oil and gas	5	543
Shale, gray	10	548
Sandstone, gray; some gas	6	558
Shale, blue	20	564
Sand, coarse	6	584
Shale, light blue	24	590
Sand, dark gray; trace of oil	63	614
Clay and sand, hard at base	20	677
Shale, gray	20	697
Clay, blue, tough ("gumbo")	12	717
Shale, green, soft, hard at base	45	729
Clay, light gray	10	774
Clay, blue	10	784
Clay, tough, blue, sticky, with "oil colors"	90	794
Shale, blue	25	884
Shale, gray	12	909
Gravel, fine, pebbles one-sixteenth to one-fourth inch; trace of oil	12	921
Clay, blue, hard at base	18	933
Sand and clay	10	951
Clay, blue, tough	30	961
Shale, blue	20	991
Clay, black	5	1,010
Shale, laminated	5	1,015
Clay, blue	5	1,020
Shale, light gray	10	1,025
Limestone, impure argillaceous	10	1,035
Limestone and shale, alternating light and dark	35	1,045
Clay, blue	60	1,080
Total depth at end of this record	....	1,140

EASTERN OREGON OIL COMPANY.

The Eastern Oregon Oil Company, of St. John, Oreg., has begun a well in sec. 12, T. 20 S., R. 45 E., in a small gulch tributary to Cow Hollow, 11 miles southeast of Vale (No. 4, Pl. III). At the time of the writer's visit the well had reached a depth of 335 feet and had struck a small flow of gas at 250 feet, at the top of a dark sand, in which traces of oil were obtained. The oil rose to the top of the bailing water and spread almost instantaneously in films 1 to 6 inches across. (See p. 46.) The gas contained some hydrogen sulphide, as indicated by its odor. It is reported that a larger flow of oil has since been struck at greater depth, but nothing of commercial value. In October, 1909, the log was as follows:

Log of well No. 1 of Eastern Oregon Oil Company, in sec. 12, T. 20 S., R. 45 E.

Character of rock.	Thickness.	Depth.
	Feet.	*Feet.*
Sandstone, brown	50	0
Conglomerate, small pebbles one-fourth to one-half inch	35	50
Sandstone, yellow	10	85
Conglomerate	10	95
Sandstone, yellow	5	105
Sandstone, blue	50	110
Clay, blue	90	160
Sandstone, dark blue, gas at top; traces of oil below	85	250
Depth of well October 9, 1909		335

BAKER AND MALHEUR OIL COMPANY.

The Baker and Malheur Oil Company, of Baker City, Oreg., had started three small wells, all of which were too shallow in 1909 to be considered good prospect holes. Well No. 1, in the SW. ¼ sec. 4, T. 19 S., R. 45 E., 3 miles south of Vale (No. 5, Pl. III), is located on a symmetrical little dome, 1,500 feet in diameter and having dips of 5°, 7°, and 10°, probably quaquaversal, although the rocks are not well exposed on the west side. This dome bears some resemblance to those in other oil fields that have cores of salt, gypsum, dolomite, or basalt, and it will be interesting to learn whether any of these substances or oil are encountered as the well is deepened. Wells No. 2 and No. 3 were not visited but are located on Plate III (Nos. 6 and 7) from the company's description of the quarter section, etc., accompanying the logs.

Log of well No. 1, Baker and Malheur Oil Company, in the SW. ¼ SW. ¼ sec. 4, T. 19 S., R. 45 E.

Character of rock.	Thickness.	Depth.
	Feet.	*Feet.*
Loam, sandy	29	0
Shale or clay, soft, yellow	33	29
Clay, blue, tough, hard to mix	13	62
Shale, blue, soft; easy drilling	50	75
Shale, gray, harder; good drilling	20	125
Sand with seepage of water	10	145
Shale and "lime rock"	17	155
Conglomerate ("hard cement gravel")	1½	172
Shale, gray, calcareous, with much pyrite	4	173½
Shale, gray, calcareous, hard	7	177½
Shale, gray	42	184½
"Hard cement"	½	226½
Sand, gray, soft, coarse; much water, which rises 40 feet in well	23	227
Shale, light gray, soft; "show of oil"	37½	250
Sand, fine grained	2	287½
Conglomerate and gray sand with pebbles up to the size of beans; hard drilling	50½	289½
Depth of hole July 16, 1909		340

Log of well No. 2, Baker and Malheur Oil Company, in NW. ¼ NE. ¼ sec. 10, T. 19 S., R. 45 E.

Character of rock.	Thickness.	Depth.
	Feet.	*Feet.*
Dirt	10	0
Shale, gray, soft	22	10
Conglomerate, hard	8	32
Sand, "sharp"	2	40
Sand, fine, brown, or soft sandstone, with scattered pebbles as large as beans in lower part	88	42
Shale, rather hard	17	130
Sand, brown, sharp, with some gas; "greasy odor"	15	147
Shale, blue, with a few thin strata of conglomerate	20	162
Clay, "blue gumbo; hard to drill, as it would not mix with water"	10	182
Shale, blue, sandy, some water	11	192
Shale, blue, with much gumbo	74	203
Sand with very hot water, rising 60 feet in the hole	13	277
Shale, blue, hard	30	290
Depth of well August 13, 1909		320

Log of well No. 3, Baker and Malheur Oil Company, in SE. ¼ NW. ¼ sec. 29, T. 19 S., R. 45 E.

Character of rock.	Thickness.	Depth.
	Feet.	*Feet.*
Soil (and shale?)	28	0
Conglomerate, hard	6	28
Sandstone, brown	28	34
Shale, brown	28	62
Shale, mostly blue	38	90
Shale and blue gumbo	35	128
Total depth August 29, 1909		163

GRAVITY OF THE OIL.

Up to the time of the writer's visit only slight traces of oil had been noted, and the samples obtainable were too small to permit the determination of their gravity by the ordinary instrumental means. The sample of oil (see p. 36) extracted from the sandstone in Sand Hollow, 10 miles southwest of Vale, was of very light color and low viscosity, and was therefore presumably a light paraffin oil.

The following paragraphs may serve to suggest a new method of estimating the gravity of small traces of oil.

The rate of spread of a film of oil on water and under air is determined by the relative magnitudes of the three surface tensions involved and the viscosity of the oil. In a forthcoming paper by the writer the mechanism of the action considered will be explained in detail; it may suffice here to say that a light oil spreads faster than a heavy oil because its surface tension and its viscosity are lower.

In watching the escape of small gas bubbles from the bailing water of the Columbia well the writer observed that when they broke at the water surface a little iridescent film of oil spread almost instantly over the water. Possibly these bubbles were little drops of oil containing considerable gas; but the larger ones certainly consisted almost wholly of gas, probably with a thick envelope of oil on the wall of the bubble. A few drops of oil, nearly free from gas, also rose to the surface, without making a pustule, and spread with the same rapidity, after which the film was drawn out by the muddy current and carried down to the settling pit. The same phenomenon in larger quantities of oil was observed at the Eastern Oregon well. On applying the principle stated in the last paragraph it is evident that the films observed on the bailing water of these two wells were those of a very light oil, for they spread with unusual rapidity.

ORIGIN OF THE GAS AND OIL.

The always difficult question of the origin of gas and oil can not be considered adequately in a paper of this kind, especially after so hasty a reconnaissance. However, a few facts are so patent that they deserve notice, even though the conclusions drawn are necessarily tentative.

The apparent solution of this question for the Vale field may be summarized by saying (1) that throughout the region hot springs are abundant and carry inflammable gas; (2) that the Payette formation is not a likely source of the gas and oil which it contains; and (3) that the Payette formation probably rests on granite and metamorphic rocks from which these substances could not have been derived. The presentation of these facts is a strong argument for the solfataric or abyssal origin of the gas and oil. The statement may be elaborated as follows:

(1) The region is one of dying volcanic activity, as is shown by its many hot springs, active and extinct, by the great volume of volcanic products in the series of rocks, and by the presence of Pleistocene or recent volcanoes immediately south of the field.[a] The hot springs have already been described. (See pp. 33–36.) Their ultimate source is doubtless deep in the earth, and as hot water is a poor solvent of gases it is probable that the inflammable gas of the springs was not gathered in the Payette formation but came occluded in the hot water from its abyssal source. There is no way of determining how much of this upward journey was in molten magmas, but the high temperature (198½° F.) of the Vale Spring suggests that hot lavas may be present at relatively shallow depths in the underlying granite. Assuming that this water has lost 20° of its original temperature in passing through the colder rocks, and assuming a heat gradient of 1° in 50 feet and a mean surface temperature of 50° F., the water would have risen from a depth of 8,400 feet. If it was expelled from hot igneous rocks at shallower depth, which is not

[a] See Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U.S. Geol. Survey No. 217, 1903, pp. 36–59.

improbable, it must have been vaporized[a] and would then include the methane most readily. When the vapor condensed a large part of the methane and similar gases was probably driven off into the sediments.

(2) The Payette formation is probably not the original home of the oil and gas which it contains. The formation is composed of fresh-water clay, sand, and gravel, of both fluviatile and lacustrine origin. These materials are prevailingly light colored, or light-yellow sand and light bluish-gray clay. Some layers west of Weiser are bright red, indicative of completely oxidized iron, and the thick masses of volcanic ash are nearly white. The general absence of dark colors is usually considered indicative of the absence of much organic matter.

At many localities in the Idaho formation bones are common, but most of the bones were broken and their surfaces roughened by weathering before they were embedded in the sediment. Fresh-water and land shells are abundant at some places and compose a few rare, thin beds of shell limestone; but many of the shells are waterworn, most of them are broken, and those in the shell limestones were ground up during their deposition or decomposed into a limy marl containing many fragments and few complete shells. The same remark applies to the few beds of shells and fish bones found in the lower strata. The fish remains consist of separated and broken bones, teeth, plates, and scales; no complete skeletons, much less any fleshy material, appear to have been deposited. Plant remains are very scarce, and fossil leaves have been found at only a few localities. There are few if any remains of diatoms, and if present (see p. 29) they could not be marine species. The combined thickness of all the fossiliferous beds discovered would not exceed 100 feet in a total thickness of over 4,200 feet of strata which contain small amounts of gas from the top nearly to the bottom and some large deposits near the middle. In summary, the condition of the fossils, their insignificant volume, and the strong evidence of the original weathered condition of the sediments makes the Tertiary strata of the Vale field a most unlikely source of the gas and oil which they now contain.

(3) The rocks beneath the Payette formation seem equally unsuitable as the original sources of the gas and oil. The nearest shore line of the Payette beds, where lower rocks appear, is that marked by the granite mountains of Idaho, about 20 miles east of Payette. Along this mountain front Lindgren[b] found that the Payette formation rests on a base of Cretaceous or early Eocene granite, with subordinate diorite, quartz-hornblende porphyrite, and rhyolite. In that region there are no sedimentary formations beneath the Payette.

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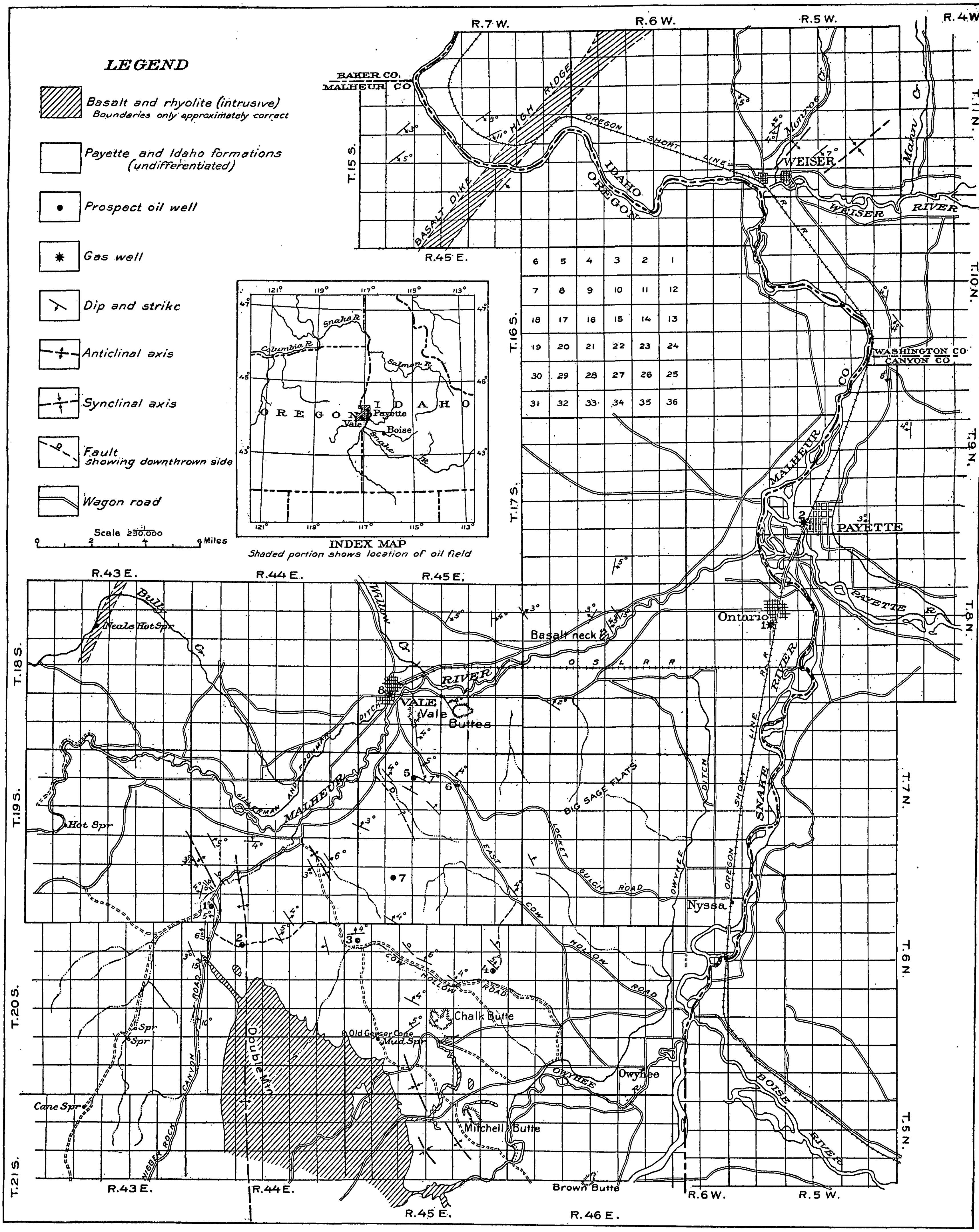
[a] See discussion of heat gradients, underground pressures, and boiling points in Chamberlin and Salisbury's Geology, vols. 1 and 2.

[b] Lindgren, Waldemar, Boise folio (No. 45), Geol. Atlas U. S., U. S. Geol. Survey, 1898.



RECONNAISSANCE SKETCH MAP OF THE PROSPECTIVE GAS AND OIL FIELD NEAR VALE, OREG., AND PAYETTE, IDAHO.

The nearest base of the Payette strata southeast of the Vale region is in the Owyhee Range, where Lindgren[a] has again found the Payette formation resting on an eroded surface of rhyolite and other igneous rocks. The northern end of this rhyolite range is in the southwest corner of the Nampa quadrangle,[b] where the upper part of the Tertiary strata (Idaho formation) are in contact with the rhyolite. This is 23 miles south of Nyssa, which is shown on the accompanying map (Pl. III).

The nearest known pre-Payette rocks southwest of the Vale region are more than 300 miles distant.[c] The marine formations in that direction, in northern California and southwestern Oregon,[d] contain little if any diatomaceous earth, but on account of their distance they need not be considered here. The intervening country is essentially volcanic, and it is not improbable that some of the rhyolite masses[e] which project as islands in the plains of Miocene basalt are older than the Payette, but no pre-Payette sedimentary rocks are known in that region.

The rocks which border the northern margin of the Payette formation in the Blue Mountains, the nearest spur of which is about 25 miles north of Vale, consist of granite, gneiss, schist, quartzite, and Carboniferous and Triassic slates and marbles. Lindgren[f] reports crinoid stems in some of the less metamorphosed Carboniferous limestone and the writer[g] has recorded other fossils from the same rocks, but the condition of these fossils clearly indicates the metamorphism to which the rocks were subjected in pre-Payette time. No indications of oil or gas have been found in any of the rocks. It would be surprising if they could retain these substances after their metamorphism, repeated folding, and erosion in both Cretaceous and post-Cretaceous time, before the deposition of the Payette formation. At the surface, moreover, the metamorphosed Carboniferous and possibly Triassic rocks are in contact with the Tertiary sediments only in the valleys of Powder River. In the Burnt River Mountains, which are the nearest outcrops of pre-Payette rocks north of Vale, nothing is seen but diorite, rhyolite, and other igneous rocks.

[a] Lindgren, Waldemar, Silver City folio (No. 104), Geol. Atlas U. S., U. S. Geol. Survey, 1904.

[b] Lindgren, Waldemar, Nampa folio (No. 103), Geol. Atlas U. S., U. S. Geol. Survey, 1904.

[c] Russell, I. C., Bull. U. S. Geol. Survey Nos. 217 and 252; also Fourth Ann. Rept. U. S. Geol. Survey, 1884, pp. 431–464; and Mon. U. S. Geol. Survey, vol. 11, 1885. Underlying granite and schist are exposed on Pueblo Mountain, 125 miles southwest of Vale, according to G. A. Waring (Water-Supply Paper U. S. Geol. Survey No. 231, 1909, Pl. III).

[d] Diller, J. S., Bull. U. S. Geol. Survey Nos. 33 and 79; also Fourteenth Ann. Rept., pt. 2, 1894, pp. 397–434; Seventeenth Ann. Rept., pt. 1, 1896, pp. 447–520; Twentieth Ann. Rept., pt. 3, 1900, pp. 7–36; also Lassen Peak folio (No. 15), Roseburg folio (No. 49), Coos Bay folio (No. 73), Port Orford folio (No. 89), Redding folio (No. 138), Geol. Atlas U. S., and other papers.

[e] See Waring, G. A., Water-Supply Paper U. S. Geol. Survey No. 220, 1908.

[f] Lindgren, Waldemar, Gold belt of the Blue Mountains of Oregon: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 551–776.

[g] Washburne, C. W., The marine sediments of eastern Oregon: Jour. Geology, vol. 11, 1903, pp. 224–229.

The rocks beneath the Payette formation northwest of the Vale region and those north of the Harney Valley field (see pp. 56–57), are similar to those beneath the southern, eastern, and northern margins of the Payette formation. So far as known, they are not rocks from which oil could be derived. However, the geology of this great area in the center of Oregon is practically unknown. In a rapid reconnaissance in 1899 the writer[a] found broad areas of Miocene basalt, beneath which, in the mountains south of Canyon, are diorite, serpentine, and similar rocks, while near Izee, 36 miles northwest of Burns, are metamorphic shales or slates, probably Triassic, which are succeeded westward by metamorphosed Carboniferous limestone. This limestone is overlain unconformably by a few hundred feet of Upper Cretaceous conglomerate and sandstone, with some sandy shale (Chico formation). Red Butte, about 20 miles northwest of Burns and over 100 miles west of Vale, is composed of marine Jurassic sandstone, probably equivalent to the Hardgrave sandstone of Taylorsville, Cal., but its red color shows its oxidized condition as well as the general absence from it of organic matter. The Jurassic sandstone and the Chico formation may underlie the Harney Valley field, but it is not probable that they extend eastward to the Vale field.

Thus, so far as the testimony of the nearest mountains shows, the rocks beneath the Payette formation in the Vale field are mainly granite and other igneous and metamorphic rocks, which are not likely sources of organic oil and gas. The pebbles in the conglomerate of the Payette formation confirm this determination, for they consist wholly of igneous and metamorphic rocks, mainly of altered chert, quartzite, quartz, and rhyolite. The only indication of any rock beneath the Payette formation encountered in the deep wells is the report of Russell[b] that a well 1½ miles southwest of Guffey, Owyhee County, Idaho, passed through 538 feet of Payette strata and at that depth encountered a rock resembling quartzite. Russell believed[c] that the Payette and volcanic rocks of the region rest on quartzite and granite, but quartzite is a comparatively rare rock in the surrounding mountains.

Although no conclusion as to the genesis of the oil and gas is warranted by the data gathered during this examination, the evidence points toward their solfataric origin.

ECONOMIC CONDITIONS.

DRILLING.

The rotary drill should make 50 to 75 feet per shift in the soft Payette rocks, which are practically the only strata encountered and which are ideal for rotary work. Progress nearly as good as this is

[a] Washburne, C. W., loc. cit.
[b] Russell, I. C., Water-Supply Paper U. S. Geol. Survey No. 78, p. 32.
[c] Idem, p. 18.

reported at the Ontario well. With cable tools, working two shifts, a progress of 12 to 30 feet a day in the Payette formation and of 4 to 5 feet a day in basalt is reported at the Columbia well for the drilling above a depth of 800 feet. Other wells report 10 to 50 feet a day.

In the writer's opinion this difference in favor of the rotary is more than overcome by the water column which constantly fills the hole to the surface when the rotary is used, causing a water pressure at the bottom that in many borings may exceed the pressure of the oil. The heavy asphaltic oils, which have relatively high surface tension and high viscosity, will not be driven far from the hole by this water pressure, and if the water is pumped out when an indication of such oil is obtained, the oil will return to the hole, even though its pressure is less than that of the entire water column. But if the oil is a light paraffin oil like that probably found in this field, and if its gas pressure is lower than that of the column of water, the water will drive the oil back through the sand as long as there is a supply of water in the well. Practical tests in Europe have indicated this; and the writer is engaged on a theoretical study of the capillary movement of oil which seems to show that water can drive all the light oils before it, because its surface tension, and therefore its capillary pressure, is nearly twice that of light oils. Of course, if the initial gas pressure on the oil exceeds the pressure of the water column in the well plus friction and capillarity, the gas will blow the well out, but this requires an initial pressure of over 440 pounds to the square inch for each 1,000 feet of depth—a pressure not reached by the gas in many fields. The writer therefore believes that the prospectors of this field are wise in using cable tools, which seem best for all prospecting in new regions except in the asphaltic fields of the Gulf coast and possibly in parts of California.

At the only well that is being sunk by contract the drilling cost is $3.50 a foot for the first 2,000 feet and $4.50 a foot for the next 1,000 feet. In the prospectus of the Ontario Cooperative Gas and Oil Company it is stated that the company has spent $35,000 in drilling its deep well, of which $27,000 was for equipment, including casing and other appliances. Caving caused much trouble in this well.

FUEL.

In this area coal is expensive and wood is very scarce—in fact, there is not a wild tree in the entire region. Sagebrush is abundant and makes cheap fuel if gathered by the most economical method, namely, by using a scraper made of a sawed-off half length of railroad iron, to each end of which a horse is hitched. The boiler at the Mammoth well requires one hayrack load of this fuel a day.

WATER.

Water is scarce and not much of it is good. After drilling has commenced, however, abundant water can generally be obtained in the first 100 or 200 feet. As a rule, this water is good and causes no marked frothing and efflorescence in the boiler, but at several places it has not been serviceable. One unusual feature in this field is the marked and irregular difference in the temperature and mineral content of the water encountered in strata penetrated at different depths in the same well. The water from one of these strata can generally be used in the boiler; that from another may be highly alkaline, or saline, or hot and sulphurous. Evidently the underground waters come from different sources and have had little opportunity to mingle. The Malheur Oil Company pipes its water from Malheur River. The other companies have drilled water wells.

TRANSPORTATION AND FORAGE.

The Oregon Short Line passes through the eastern part of the field and has a branch from Ontario to Vale. Wagon roads are far apart, but are serviceable for heavy hauling.

Grass is not abundant, especially late in summer. The country is practically uninhabited, except in the alluvial valleys of the permanent streams.

LAND OWNERSHIP.

Most of the land still belongs to the Government. Large tracts of alternate sections granted in early days belong to the Dalles and Military Road Company and the Willamette Valley and Cascade Mountain Wagon Road Company or their successors, and a relatively small amount, all in the alluvial valleys, belongs to settlers. Some of the companies, notably the Ontario Cooperative Gas and Oil Company and the Oregon Oil and Gas Company, have considerable leased land. The other companies, besides holding a small amount of leased or owned land, have mainly claims under the placer act to locations on government land. The government land is all withdrawn from entry, and no titles can be obtained until a method of disposing of the national oil and gas lands has been determined.

SUMMARY.

The only sedimentary strata in the region are fresh-water Tertiary fluviatile and lacustrine clays, sandstones, and conglomerates, which belong to the Payette and Idaho formations and have a minimum thickness of 4,200 feet near Ontario, Oreg. The structure is subdued, dips of 3° to 7° being the rule, with exceptional higher dips near igneous intrusions. The major structural feature is a broad syncline in the Snake River valley, west of which is an anticline with an igneous core known as Double Mountain. A few minor low anticlines and domes are indicated at various places.

Some very small traces of oil have been found, and some larger, probably valuable quantities of gas.

The strata containing the gas and oil are deposits of weathered terrestrial material, unusually free from organic matter, and are therefore not regarded as a probable original source of the gas and oil. These strata rest on granite and other igneous and metamorphic rocks, which are equally improbable sources of organic gas or oil. Hot springs are abundant and contain inflammable gas. It is suggested that the hot waters introduced the gas into the field from abyssal sources.

CONCLUSIONS.

This field bears no geologic resemblance to any other oil or gas field in the United States, with the possible exception of the prospective gas field at Salt Lake. This statement should in no way detract from the possible value of the field; in fact, the repeated attempts to compare the strata and phenomena here with those of the California fields are both unnecessary and unjustifiable. The comparison shows disregard for the history of oil developments, for the erratic fluid has repeatedly been found in places where no previous experience warranted a prediction of its occurrence. No oil would have been found in the Trenton limestone of Ohio if the prospectors had insisted on drilling only in sands and shales like those of Pennsylvania; no oil would have been found in the fissured syncline of shale at Florence, Colo., if the sands and anticlines of the Eastern States had been considered essential; the mounds in Texas and Louisiana, which have cores of salt, would never have developed into oil fields if the phenomena of northern fields had been considered necessary. In parts of Europe the presence of menilite shales is thought desirable; in California the presence of diatomaceous earth is important; in Mexico some of the best fields have been developed near volcanic necks and dikes. Large faults and complex structures have been commonly tabooed as fatal to oil fields, yet there are good oil fields in Roumania, Galicia, and California, where the rocks are not only overturned and faulted, but the faults seem to have promoted the migration of the oil and in some places even to have sealed permeable strata by bringing them into juxtaposition with impermeable rocks, thereby creating instead of destroying an oil reservoir. Although much valuable knowledge can be obtained in any oil field, the greatest care must be used in applying this knowledge to another field, for its improper application will be more injurious than beneficial.

Perhaps the safest rule at present is to disregard theories of origin and to consider each field as a unit in itself, in which two things are desirable—(1) probable reservoirs and (2) traces of oil or gas.

(1) The nature of the reservoir depends on the local geology. The reservoir may be a sand in shale (one at least is a conglomerate in sand); it may be a cavernous or openly crystalline limestone or dolomite; it may be a fissure in almost any rock. A reservoir of the fissure type is rarely capable of surface estimation;[a] the others are indicated by the stratigraphy. If the reservoir is a porous bed, it must be sealed in some way, either by a less permeable rock, such as clay or shale, or by a part of the same bed which is charged with water or clogged with asphalt. At many places the oil reservoir is a lenticular sand of which there is no surface indication and which may contain oil in almost any structural position. With the possible exception of the water-sealed monocline the most common reservoir is a porous bed inclosed in shale and bent in an anticlinal arch or bench.

(2) Many oil fields have been developed near seeps or other traces of oil or gas, some fields have had no signs of oil on the surface, and many fields have been complete failures notwithstanding the best surface indications. It seems reasonable, however, to believe that surface shows of oil are favorable indications and that the larger they are and the nearer they are to possible oil reservoirs the better will be the chances of getting oil. The character of the product will probably be similar to that of the traces, but oil is usually lighter underground than it is in seeps at the surface.

These principles may be applied to the Vale-Payette region by noting—(1) that there are numerous beds of sand and conglomerate, some of the conglomerate beds being lenticular, embedded in comparatively impermeable clay and shale and gently folded in a few small, low arches and domes, in a position favorable to the concentration of oil and gas in reservoirs; and (2) that signs of gas are abundant and widely distributed, possible commercial quantities being found in three wells in the Vale-Payette field and in one well in the Harney Valley field, 100 miles farther west. There are a few traces of oil, which, however, are very small.

The logical conclusion is that the chances for developing a gas field are good and that the chances for developing an oil field are slight, though not to be wholly disregarded. No stronger conclusions are warranted by geologic study. The oil men must decide how thor-

[a] For a study of oil-bearing fissures in shale, see paper on the Florence oil field, Colorado: Bull. U. S. Geol. Survey No. 381, 1910, pp. 521-525.

oughly the wells already drilled have tested the field.[a] Except for an artesian well 1,700 feet deep there were, in October, 1909, only two borings in the field more than 1,500 feet deep, the depths of which were 3,596 and 1,506 feet. Outside of the Vale-Payette field there is a great area of the Payette and Idaho formations in which gas is reported to occur at a few places, but the status of these will be scarcely affected by the present development.

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[a] The condition of the principal wells in May, 1910, is reported by Mr. T. W. Davidson to be approximately as follows: The Malheur well, depth 1,680 feet, with new traces of gas; the Columbia well, depth 975 feet, nearly all in shale; the Mammoth well, depth 1,280 feet, in shale; the Ontario Cooperative well, depth 3,650 feet, diameter 6 inches at bottom, shale getting harder; the Eastern Oregon well, depth 815 feet, the last 80 feet being sandstone, except for an 8-foot parting of red clay. Mr. Davidson reports that several of the wells have found new traces of gas and oil, but that none of them has made a commercial output.

GAS PROSPECTS IN HARNEY VALLEY, OREGON.

By Chester W. Washburne.

The gas prospects in Harney Valley, central Oregon, are located at places near Malheur and Harney lakes, 90 to 105 miles directly southwest of Vale. The region is underlain by Tertiary lake beds, which are probably equivalent to the Payette and Idaho formations of the Snake River valley.

The valley was visited by the writer in 1899, before prospecting began, and the following information about the wells has been kindly furnished by Mr. R. B. Post, of the water-resources branch of the Geological Survey, stationed at Burns, Oreg.; by the officers of the Harney Valley Oil and Gas Company; and by others.

In February, 1909, a strong flow of gas was struck at a depth of 357 feet, in a well drilled for water by John Leake about 15 miles south of Burns, Oreg., in the SW. ¼ sec. 28, T. 25 S., R. 32 E. The gas is said to have forced the tools out of the well and to have "hurled sand and salt water into the air to a height of 40 feet." In October, 1909, the flow of gas still continued, but with diminished pressure and small volume.

From a sample of the sand thrown out of this well, a "very small quantity of oil" was obtained by C. E. Bradley, chemist of the United States Experiment Station, Oregon Agricultural College, Corvallis, Oreg.

The well is only 2 inches in diameter at the bottom and was drilled with a "light hydraulic rig."

Along the north shore of Harney Lake, 12 to 15 miles southwest of the Leake well, mentioned above, 11 prospect wells, 74 to 252 feet deep, have been drilled by the Harney Valley Oil and Gas Company, of Burns, Oreg. The wells are half a mile apart in secs. 20, 21, 27, 28, 29, and 30, T. 26 S., R. 30 E.

Traces of gas are reported from all the wells, the heaviest flows being derived from depths of 74, 150, and 252 feet, from different wells. The quantity of gas obtained was not of commercial significance, but the wells are too shallow to test the field, and until deeper wells are drilled no conclusion can be formed as to the amount of gas available.

All the wells, including the Leake well, were "drilled with a light hydraulic rig, with which it was not possible, on account of the heavy gas pressure, to penetrate below the sand in which the gas was struck."

The strata penetrated by the wells in Harney Valley are of the same general character as those in the Snake River valley, with which they are probably continuous except as they may be interrupted by two or three ridges of volcanic rocks. Observations made by the writer in 1899 indicate that the strata in Harney Valley may belong to the series of Tertiary fluviatile and lacustrine deposits which, on the eastern border of the State, have been named the Payette and Idaho formations. The sedimentary rocks are certainly of fresh-water origin, although the oil prospectors of the locality believe without reason that they are marine deposits. The fossil shells that are preserved in abundance at different horizons have been identified as those of fresh-water species. The nearest marine deposit known to the writer is the Jurassic red sandstone at Red Butte, in the foothills of the Blue Mountains, about 20 miles north of Burns.[a]

The rocks of Harney Valley have a general synclinal structure, the dip steepening toward the central part of the basin to angles ranging from 3° to 10°. Indications of minor folds and faults have been seen, but geologic work in that region is still too imperfect to permit the exact location of these features of the structure.[b]

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[a] Notes on the marine sediments of eastern Oregon: Jour. Geology, vol. 11, 1903, pp. 224–229.

[b] Since the above report was written a paper by Gerald A. Waring on the geology and water resources of the Harney Basin region, Oregon, has been published by the Geological Survey as Water-Supply Paper 231, from which it appears that the sediments in Harney Basin overlie the lavas and probably do not exceed a few hundred feet in thickness. They therefore can not be equivalent to the Payette formation, as suggested above. This new information makes it improbable that more than a small amount of shallow gas can be obtained in the basin.

PRELIMINARY REPORT ON THE GEOLOGY AND OIL PROSPECTS OF THE CANTUA-PANOCHE REGION, CALIFORNIA.

By Robert Anderson.

INTRODUCTION.

SCOPE AND PURPOSE OF REPORT.

This report is a preliminary statement of the results of field studies made during the summer and fall of 1909. Its object is to give a brief outline of the geology of the region just north of the Coalinga oil field, on the west side of the San Joaquin Valley, California, and to consider whether or not the geologic conditions that have caused the immense accumulations of oil in the Coalinga field are repeated along the flank of the Diablo Range farther north. Its main purpose will be achieved if it serves to point out the parts of this region in which there is some probability of discovering oil and to set at rest expectations of finding oil in parts in which the conditions for its accumulation are unfavorable.

The examination of this region was undertaken as a continuation of the survey of the Coalinga field, and the present paper may be regarded as a supplement to the report on that field.[a] A more complete report on the Cantua-Panoche region, with topographic and geologic maps, will be published later.

ACKNOWLEDGMENTS.

In the geologic work the writer was assisted by Mr. R. W. Pack, who aided in solving the many problems involved in the study. Mr. Olaf Jenkins helped to make the work successful by rendering assistance in conducting the camp, in a region where exploration is at times trying.

The Cantua-Panoche region had been previously visited by several geologists, to whom acknowledgments are due for the suggestions their reports have afforded. These reports are listed below in chronological order.

[a] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, California: Bull. U. S. Geol. Survey No. 398, 1910.

Whitney, J. D., and Gabb, W. M., Geol. Survey of California, Geology, vol. 1; Paleontology, vols. 1 and 2, 1864–1869.

White, Charles A., On the Mesozoic and Cenozoic paleontology of California: Bull. U. S. Geol. Survey No. 15, 1885.

Becker, George F., Notes on the stratigraphy of California: Bull. U. S. Geol. Survey No. 19, 1885; also, Geology of the quicksilver deposits of the Pacific slope: Mon. U. S. Geol. Survey, vol. 13, 1888.

Turner, H. W., and Stanton, T. W., Notes on the geology of the Coast Ranges of California: Am. Geologist, vol. 14, 1894, pp. 92–98.

Stanton, T. W., Faunal relations of the Eocene and Upper Cretaceous on the Pacific coast: Seventeenth Ann Rept. U. S. Geol. Survey, pt. 1, 1896, pp. 1011–1048.

Anderson, Frank M., A stratigraphic study in the Mount Diablo Range of California: Proc. California Acad. Sci., 3d ser., Geology, vol. 2, No. 2, 1905, pp. 156–248; also A further stratigraphic study in the Mount Diablo Range of California: Proc. California Acad. Sci., 4th ser., vol. 3, 1905, pp. 1–40.

The papers by F. M. Anderson give a fuller description of the geology of the region than the others, and they have been found especially suggestive regarding structural and stratigraphic features. None of the papers cited deal with oil. The most valuable aid in the work was derived from the excellent topographic map made as a preliminary step to this investigation by Messrs. R. M. La Follette, E. P. Davis, T. H. Moncure, J. E. Blackburn, and J. H. Sinclair, topographers of the United States Geological Survey.

SUMMARY OF CONCLUSIONS.

The Cantua-Panoche region as a whole does not promise to be an extension of the Coalinga oil field, but in certain areas within it the rocks are oil bearing and the geologic conditions fairly good, so that their possibilities deserve careful consideration. One area in particular presents conditions favorable for the accumulation of oil and may afford productive wells. This is on the north side of the east end of the Vallecitos, 24 miles from the nearest producing wells in the Coalinga district. Other areas around the Vallecitos will probably yield petroleum in small quantities. An area near Tumey Creek, northwest of Ciervo Mountain, gives considerable promise. These areas as well as several others that present less favorable indications will be discussed in the body of the report.

GEOGRAPHY AND TOPOGRAPHY.

The area examined and discussed is a long strip of country on the northeast flank of the Diablo Range, extending for about 50 miles northwestward from the Coalinga district. It extends from the northern part of T. 19 S. (Mount Diablo base line) to Little Panoche Creek, in T. 13 S., covering the western edge of Fresno County and the eastern edge of San Benito County. Its width throughout most of the distance from the central portion of the Diablo Range to the edge of the San Joaquin plain is 10 to 15 miles, and it covers an area of about 600 square miles. The region includes four main topographic features—(1) the arid western border of the San Joaquin Valley, a wide, plain, slightly inclined at the edge of the hills owing to the sloping alluvial fans; (2) the foothills and mountain ridges, outliers of the main range, which are arid and almost entirely destitute of trees or bushes because they lie to the lee of the range with respect to the rain-producing winds; (3) the interior structural valleys, small, relatively level-floored dry basins inclosed as pockets between the outlying hills and the main range; (4) the ridges forming the crest or spurs of the Diablo Range, which are clothed with a fairly thick cover of brush and a picturesque open forest of pine, cedar, juniper, oak, and other trees and which give rise to perennial small streams that lose themselves in the dry, porous rocks of the foothill region or the valley border.

The amount and the comparative sharpness of the relief in this region is illustrated by the rise of the surface across a belt less than 20 miles wide from an elevation above sea level of 200 to 300 feet, the general level of the San Joaquin Valley, to 5,258 feet on San Benito Mountain, the highest summit of the Diablo Range. The general rise from the valley to the summit of the foothills or mountain outliers in a distance of 5 to 7 miles is from 500 feet at the base of the hills to heights ranging from 2,000 to 3,000 feet. At the southern end of the region an altitude of 4,153 feet is reached at the Joaquin Rocks, on the ridge of the same name, within 7 miles of the valley's edge. In the center of the region, between Cantua and Silver creeks, the summit of the foothills, in the same distance from the valley, reaches an elevation of 3,300 feet on Ciervo Mountain.

Owing to the scarcity of water this region is sparsely inhabited and is used principally as a range for cattle and sheep. In the Vallecitos and Panoche valleys, however, there are several farms where hay and grain and other products are raised. The only village in the region is the old settlement around the New Idria quicksilver mine, near the base of the mountains. The roads giving access to the region are the stage road leading from New Idria northwestward through Panoche Valley and across the Diablo Range to the railroad at Tres Pinos, about 60 miles away; the stage road from New Idria down Silver Creek and across the San Joaquin Valley to the railroad at Mendota, about 40 miles away; the road from New Idria southward to the headwaters of Los Gatos Creek and thence westward toward the Salinas Valley or southeastward toward Coalinga and the San Joaquin Valley; the road from Panoche Valley northeastward through Little Panoche Valley to Los Banos and other settlements in the San Joaquin Valley; and the road from the mouth of Big Panoche Creek southeastward along the border of the San Joaquin Valley to Coalinga. From the last-named road a branch extends a few miles up Cantua Creek.

GEOLOGY.

GENERAL FEATURES.

The general geologic features of the Cantua-Panoche region may be summarized by stating that they present a fairly regular continuation of those of the adjoining Coalinga district, which have been described in a previous and more complete report.[a] In accord, however, with the characteristic variability of the Cretaceous and later formations of the west coast, the strata and the structure present important changes in detail along their strike northwestward from the Coalinga district.

The main stratigraphic divisions are the same as those in the northern part of the Coalinga district, namely, the Franciscan formation (Jurassic?), with its great body of associated serpentine; the Cretaceous rocks, embracing the middle and upper divisions of the Coalinga district and including a considerable thickness of superadded beds; the Eocene, comprising brilliant white friable sandstone, believed to represent the Tejon formation, and underlying clay beds probably of Tejon age but representing perhaps the Martinez formation; the Eocene (?), consisting of the white organic shales doubtfully referred to the Eocene in the Coalinga district; the lower Miocene, composed of sandstone and shale, representing either the Vaqueros or the Monterey shale, overlain by beds composed of flakes and bowlders of serpentine locally called "the Big Blue;" the middle Miocene, consisting of the northward continuation of the Santa Margarita (?) formation of the Coalinga district; the upper Miocene, composed of the northward continuation of the Etchegoin and Jacalitos formations; the Pliocene, made up of the northward continuation of beds mapped as the Tulare formation in the Coalinga district; and the Quaternary alluvium and terrace deposits. These formations, with the exception of the Pliocene and later deposits, are for the most part marine sediments. There are no igneous rocks except the serpentine associated with the Franciscan formation and one small intrusion of basalt in the Miocene in the northwestern part of the region.

The beds that are important as sources or reservoirs of oil in this region, as in the northern part of the Coalinga district, are the purple shale in the upper portion of the Cretaceous system, the white shale which overlies the Eocene white sandstone and is here referred to as Eocene (?), and the lower Miocene sandstone and shale. The Franciscan formation, the main body of Cretaceous beds, and the later Tertiary formations are not known to carry oil in any part of the region.

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[a] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, California: Bull. U. S. Geol. Survey No. 398, 1910.

A regularly dipping series of strata which involves all the formations above enumerated begins on the north flank of the Coalinga anticline and continues northwestward from the Coalinga district for a distance of about 20 miles. The Franciscan rocks, the oldest in the series, and the associated serpentine appear on the summit of the Diablo Range along the axis of the great anticline that forms this range; the Upper Cretaceous series forms the main mass of the mountains on the northeast side of the summit of the range; and the Tertiary beds underlie much of the foothill belt. The beds dip northeastward, generally at a moderate angle, toward the Great Valley. Some miles north of Cantua Creek, in the inner foothill region and in the mountains, the northeastern flank of the geanticline of the Diablo Range is complicated by minor folds, but along the outer hills it continues unbroken at least as far as Little Panoche Creek. In the area between Ciervo Mountain and Big Panoche Valley it is modified by the presence of a large anticlinal fold, which runs across it obliquely from west-northwest to east-southeast. This anticline passes lengthwise through the mountain group separating the Panoche Valley from the Vallecitos, crosses Silver and Tumey creeks, and dies out in the region of Ciervo Mountain. It will be referred to as the Ciervo anticline. The strata uplifted by the anticline form a region of elevated outliers of the main mountain range. The syncline corresponding to it forms the depression of the Vallecitos—the "little valleys" which separate the mountains from this outlying group. This syncline may be called the Vallecitos syncline. Another cross structure, probably of similar general type but more complicated, occurs still farther north and produces the large depression forming the Panoche Valley and the block of the Panoche Hills north of it. These cross structures are accompanied by faults. As they approach the Great Valley they plunge southeastward, and the folds thus die out upon the uniform northeastward-dipping structure of the outer foothills.

FRANCISCAN FORMATION (JURASSIC?).

The complex association of rocks grouped under the name Franciscan formation constitutes the basement upon which the other formations were laid down. It appears only in the central portion of the Diablo Range, south of New Idria and west of Panoche Valley. It is made up of many varieties of rock, including gradations from unaltered sediments, such as sandstone and shale, to products of complete metamorphism, such as glaucophane and other schists, and strange rocks to which no accepted name has been applied. In the vicinity of the New Idria quicksilver mine the altered sedimentary rocks of this formation near their contact with the overlying Cretaceous rocks are richly veined and impregnated with cinnabar.

Serpentine is intimately associated with the sedimentary and metamorphic rocks and predominates in area over them. Serpentine covers most of the summit region around San Benito Mountain and back of New Idria and appears also west of Little Panoche Valley. It is not properly a part of the Franciscan formation, being intrusive and of later origin, but for convenience of description it is considered with the Franciscan. The chief areas of sedimentary and metamorphic rocks of the Franciscan within the region studied are just south of New Idria and in the hills forming the divide between Panoche and Little Panoche valleys.

CRETACEOUS SYSTEM.

CORRELATION.

The Cretaceous beds of the Cantua-Panoche region represent the middle and upper divisions of the rocks described in the Coalinga report as the Knoxville-Chico; they are believed to belong as a whole to the Upper Cretaceous. There is no evidence of the presence in this northern region of the lower division of those rocks, which in the Coalinga district was thought to be probably of Lower Cretaceous age and therefore to represent the Knoxville formation. The field examination here reported, however, has established the fact that a thick body of Cretaceous rocks is present in this region above the uppermost Cretaceous beds of the Coalinga district, making the record of the Upper Cretaceous in this field much more complete.

SUBDIVISION.

In addition to this difference in the portions of the column represented in the two regions, the beds undergo changes in their lithologic character in short distances, making it difficult to ascribe definite limits to the various members, or even the major divisions, or to correlate them accurately from place to place. In the southern part of the Cantua-Panoche region there are six main divisions of the Cretaceous system, distinctly set off from each other by lithologic differences. Toward the northern part of the region a gradual change in the lithology of the beds takes place and it is not possible to set constant limits for these divisions.

1. Of the six divisions referred to, the lowest, consisting chiefly of dark shale, has a thickness of several thousand feet and is the continuation of the middle division of the Knoxville-Chico of the Coalinga district. It is believed to be of Chico age. It forms the belts of low relief at the headwaters of Cantua and Salt creeks, between the serpentine on the summit of the range and the high ridges of concretionary sandstone extending northwestward from the Joaquin Rocks.

2. The concretionary sandstone forming these ridges is the next division above and is the same as the main concretionary sandstone of the upper division of the Knoxville-Chico in the Coalinga district. It has a thickness of over 2,000 feet on Joaquin Ridge and along the belt of rugged mountains which it forms between that ridge and the upper canyons of Cantua Creek, but is much thinner farther west, toward Idria. It forms the larger part of the hills north and south of Panoche Valley, where also its thickness is great. Typical Upper Cretaceous fossils are scattered sparingly throughout the beds.

3. The sandstone described above is overlain by about 1,000 feet of beds consisting largely of dark shale and carrying Chico (Upper Cretaceous) *Ammonites*, *Baculites*, and other fossils.

4. The fossiliferous shale mentioned is succeeded above by a second mass of concretionary sandstone, about 200 feet thick, which in the Coalinga district is the highest member of the tawny, concretion-bearing sandstone so characteristic of the Upper Cretaceous.[a]

5. The fifth division of the Cretaceous system—the most important division to the oil prospector—lies above the tawny sandstone. It consists of beds of black and purplish shale aggregating 1,000 feet or more in thickness and forming throughout most of the foothill belt of the Cantua-Panoche region a zone markedly distinguished by its purple color, its comparatively smooth and low topography, and its tendency to support a scattering growth of small, deep-green juniper and oak trees, which give it prominence in a region generally devoid of trees. This zone will be referred to as the purple shale. It is the same shale that yields the light oil obtained about Oil City, in the Coalinga district, and is therefore of special interest in the present discussion of this region. This purple shale is of a peculiar type, unlike any that has been observed in the Cretaceous rocks in other regions. It is a compact, brittle, thinly laminated siliceous and calcareous clay shale, full of impressions of foraminifers, probably diatomaceous, and bearing a strong resemblance to the more argillaceous phases of the diatomaceous and foraminiferal shale occurring in different Tertiary formations, such as the shale overlying the fossiliferous Eocene in this region and the Coalinga district, the Monterey shale of the outer Coast Ranges, and the shale overlying the beds containing the Santa Margarita fossils in the Diablo and Temblor ranges. This Cretaceous shale shows little of the white color common to the other formations mentioned; but its characteristic purplish brown, changing to a lavender shade on weathering, is a feature common to Tertiary organic shales found at many places. The cause of its purplish color is not certainly known, but in places in the Tertiary formations mentioned a similar hue seems to be the result of petroleum stain, and petroleum probably produced the color in the Cretaceous shale.

[a] See Bull. U. S. Geol. Survey No. 398, 1910, pp. 56, 59.

There are other indications, to be mentioned later, that this shale has been impregnated with oil throughout most if not all of this region. This stratigraphic division, of which the purple shale is the most prominent member, contains also a large amount of black clayey shale, especially in its lower half, which nearly everywhere consists chiefly of such material mingled with lenticular masses of white and yellow sandstone. In most places beds of black clayey shale mingled with sand lie upon the purple shale and seem to grade upward into the overlying beds. The purple shale contains many oval concretions of grayish-white shaly limestone carrying fossil mollusks indicating the Cretaceous age of the beds. Such fossils also occur sparingly in the purple shale itself. They include at least three genera of ammonoids, besides *Pecten, Nucula,* and other genera. The discovery of the Cretaceous age of this shale was one of the most interesting results of the field study of this region, for it had previously been regarded as Eocene.

In the northern part of the Coalinga district and the southern part of the Cantua-Panoche region—that is, in the area between Pleasant Valley and Salt Creek—the purple shale is the highest known Cretaceous rock and is overlain by beds of clayey shale containing Eocene fossils in their upper portion. Within the area mentioned there is a mass of 200 feet or more of dark clayey beds above the purple shale in which diagnostic fossils have not been found and which may belong either to the Cretaceous or to the Eocene series. It seems reasonable to assume that the top of the typical purple shale is the top of the Cretaceous system, as it is the horizon marked by the greatest lithologic change. That this change may be of little importance, however, is shown by the facts that the purple shale grades downward into dark clayey shale and that, a few miles farther northwest, it grades upward also into dark clay and shale known to be Cretaceous and similar to that overlying it here. Notwithstanding the surprising lack of apparent stratigraphic break between these two great systems, the Cretaceous and Tertiary, there must be an unconformity between them, because the important sixth division, next to be described, is here lacking.

6. The sixth division, lacking in the southern part of the region, appears as a lens of sandstone about a mile south of Salt Creek, near the line marking the top of the purple shale. In a very short distance it attains a thickness of several hundred feet, and from Salt Creek it continues northwestward, increasing rapidly in thickness until within 12 miles it attains, in the region northeast of Idria, the remarkable thickness of over a mile. It is separated from the purple shale by about 100 feet of dark clay shale. Lithologically this sandstone is an almost exact replica of the lowest concretionary sandstone already mentioned, and when it was first observed, in the region

northeast of Idria, it was mistaken for that lower sandstone. Its position so high in the series and above the purple shale—at that time considered Eocene—was at first a great puzzle, and the discovery that it was a distinct formation, adding several thousand feet of strata above the highest Cretaceous beds recognized farther south along the flank of the range, was another interesting result of the field work. In addition to the evidence afforded by the strong resemblance of this concretionary sandstone to the typical Cretaceous concretionary sandstone of lower horizons, its Cretaceous age is indicated by the discovery of ammonites at three different places in float that could not have come from any other rocks. Fossils are very rare in these beds and search for characteristic forms in place proved fruitless. These strata are the highest Cretaceous beds yet recognized in this region, and their top is believed to mark approximately the Cretaceous-Tertiary contact, but there is thus far no proof that the line may not lie somewhere within the overlying dark clay shale. Though so thick in the vicinity of Idria, the upper concretionary sandstone is thinner again toward the north and disappears in the outer foothills northeast of Tumey Creek, leaving the line of separation between the Cretaceous and Eocene again in doubt, at the base of or within the dark clay that overlies the purple shale of the Cretaceous.

TERTIARY SYSTEM.

EOCENE SERIES.

The known Eocene of this region is divisible into two parts, namely, the dark clay shale already mentioned as overlying the Cretaceous and a prominent body of sandstone characterized through most of the region by its brilliant white outcrops and typical Tejon fossils. Upon this sandstone lies a thick formation of light-colored organic shale which in the Coalinga report was included provisionally in the Tejon formation, but its age is in doubt and it will here be described separately.

Dark clay.—The two highest members of the Cretaceous system already described are overlain throughout the region southeast of Silver Creek by fine-grained, relatively soft material consisting usually of blackish, impure clay or clayey shale but locally sandy and lighter colored. This clay contains good Eocene fossils in its upper portion and is thought to be referable as a whole to the Eocene series, although, as already stated, it may be in part of Cretaceous age. The contact of this dark clay with the underlying known Cretaceous beds does not have the appearance of being a line of great stratigraphic importance, although it must represent, along most of its course at least, an important unconformity. The dark clay ranges in thickness from 400 to 800 feet along the foothills, but is much reduced in thickness on the southern flank of the Ciervo anticline. A typical exposure may be seen in a belt of low relief that extends southeastward from Salt Creek, where, together with the purple shale of the Cretaceous which in that region immediately underlies it, the clay forms a little valley between the mountains and the foothills.

White sandstone.—The next division above the dark clay already described is one of the most conspicuous in this region and, though subject to marked local variations, is likewise one of the most constant. Throughout the greater part of the foothill region it is from 100 to 300 feet thick and consists of brilliantly white friable sandstone. Over considerable areas this sandstone is interbedded with brownish carbonaceous shale containing lenses of lignite. Locally the dark clay shale below is sharply separated from the white sandstone above, but in general the two are very closely associated and appear to belong to one epoch of deposition, as is indicated by the well-defined lenses of white sandstone that occur in places entirely within the dark clay shale, by the apparent transition between the two in places, by the seeming complete merging of the white sandstone into the clay in at least two places and the merging of the clay into the sandstone at other points, and by the similarity of the fossil faunas. The white sandstone and carbonaceous shale beds are to be correlated with the Tejon formation. The underlying clay is probably part of the same formation, although there is a possibility that the Martinez may be represented in it. These two divisions, together with the closely associated organic shale next to be described, were referred to in the report on the Coalinga district as the Tejon formation.

EOCENE (?).

Overlying and closely associated with the white sandstone of the Eocene is a thick body of diatomaceous and foraminiferal shale which is probably Eocene in age but may be later. This shale is constant throughout the Cantua-Panoche region as well as the Coalinga district, where it was considered the upper member of the Tejon formation (Eocene), and owing to its individuality and its well-marked outcrops of white siliceous shale it is a prominent stratigraphic unit. It is important in the present connection because it is regarded as the source of a large part of the petroleum of the Coalinga district and is petroliferous in portions of the region here under discussion. The average thickness of this formation is 1,000 feet. Its principal constituent is white or brownish, thinly laminated diatomaceous shale in every respect like the Monterey shale (middle Miocene) of the outer Coast Ranges, including all gradations from a soft white "diatomaceous earth" to porcelaneous shale and black flint. The unaltered or only partly silicified shale is predominant.

Shale of less purely organic origin, in which argillaceous and even sandy material is abundant, is interbedded in the formation, especially in its lower half, which in places assumes a purplish-brown or locally even a dark color. Calcareous layers and concretions are numerous, and in places in the formation gray sandstone is an important constituent. Sandstone dikes are also numerous. In places there is a marked appearance of a gradation between the fossiliferous Eocene white sandstone and this overlying shale. This close relationship may indicate that the shale is of Eocene age, and the formation will therefore be referred to as Eocene (?) until more definite evidence as to its age can be obtained.

LOWER MIOCENE.

Sandstone and shale.—The epoch of deposition of the organic shale just described was followed by an epoch during which uplift and tilting of the strata took place, causing all of this region to rise above the sea and subjecting the shale to erosion. This episode is recorded by the line of angular unconformity at the base of the next overlying formation, which was laid down in early Miocene time as a marine near-shore deposit of sand, pebbles, fine clay, organic sediment, and shells upon the truncated edges of the slightly upturned siliceous shale. The formation thus deposited is the continuation of that described as the Vaqueros sandstone (lower Miocene) in the report on the Coalinga district. In the eastern part of the Cantua-Panoche region, in the hills surrounding the Vallecitos, this formation contains a fauna somewhat different in aspect from that in the Coalinga district or from any other well-known fauna of the Coast Ranges. This fauna, together with the presence in the formation in the same part of the region of considerable masses of siliceous diatomaceous shale, which occurs only in thin zones in the northern part of the Coalinga district and is absent in the southern part, suggests a possible equivalence of the formation to the lower portion of the Monterey shale in the region nearer the coast and a gradual transition westward from the sandy and gravelly strata at the eastern edge of the Coast Range to the purely organic sediments in the coastal belt. The fauna of these beds in the Cantua-Panoche region is characterized by such forms, among others, as *Turritella ocoyana*, *Pecten andersoni*, *Pecten propatulus*, and teeth of the Sirenian *Desmostylus*. Any correlation of sandy fossiliferous strata with the Monterey shale is difficult to make, owing to scant knowledge of the fauna of Monterey time. Hence the suggestion of the possible equivalence of the formation to the lower part of the Monterey shale is conjectural.

Along the border of the San Joaquin Valley these lower Miocene beds consist of about 400 feet of fossiliferous sand and sandstone, varying in texture from fine grained to pebbly. Some of the more fossiliferous layers, cemented by the calcium carbonate of the shells, are very hard and form a belt of prominent outcrops and hills facing the lower foothills. A separate area of beds occupying a similar position in the column and probably once continuous with those in the outer foothills occurs around the Vallecitos. There they are 700 to 800 feet thick and consist of fossiliferous sand, sandstone, and conglomerate interbedded with thick beds of siliceous diatomaceous shale like the underlying Eocene (?) shale. The lower Miocene beds are of importance in connection with the problem of oil accumulation because they form the cap of the organic Eocene (?) shale here, as in the Coalinga district, and because they are oil bearing at several places around the Vallecitos.

The Big Blue.—The lower Miocene sandstone and shale above described are overlain along the foothills by 50 to 150 feet of beds formed almost entirely of serpentine flakes and bowlders. These beds are the continuation of those forming the Big Blue of the Coalinga field. The name is in use among the oil-well drillers and is especially applicable in the southern part of the Cantua-Panoche region, where this member constitutes a prominent feature of the landscape, owing to its pronounced serpentine blue color and its tendency to collapse and spread in bare heaps of serpentine débris over the hill slopes. This member is almost entirely unfossiliferous and affords little basis for correlation. It was tentatively classed with the overlying middle Miocene in the Coalinga district, but evidence obtained farther north, including the discovery of a few marine fossils of an early Miocene type, indicates that it more properly belongs with the underlying beds. These fossils also indicate that it was a marine deposit.

The Big Blue is so completely made up of serpentine fragments that its outcrops look very much like the piles of weathered serpentine covering the large area of this rock in place around San Benito Mountain. Numerous huge bowlders of hard serpentine occur in the Big Blue and when half buried in the collapsed strata appear somewhat like outcrops of rock in place. These appearances have led some observers to believe that these are intrusions of serpentine in the Tertiary rocks and to conclude that the occurrence of such igneous intrusives spoiled any chances for the accumulation of oil in this region. The sedimentary nature of these deposits proves this opinion to be erroneous, and there can be no doubt that the serpentinous material was derived from the erosion of the serpentine associated with the Franciscan formation, which must have been exposed over a large area near by during this part of Miocene time. The Big

Blue is restricted to the hills along the border of the Great Valley and does not appear around the Vallecitos.

MIDDLE MIOCENE.

The Big Blue appears to be overlain unconformably by fossiliferous beds corresponding to the Santa Margarita (?) formation of the northern part of the Coalinga district. These beds include in their lower part the prominently outcropping sandstone containing the big oyster *Ostrea titan*, the big barnacle-like form *Tamiosoma gregaria*, the sea urchin *Astrodapsis whitneyi*, and other fossils, this sandstone being the one referred to in the Coalinga report as the *Tamiosoma* zone. The formation is mainly sand and sandstone of variable texture but contains some interbedded clay and shale and locally a pronounced basal conglomerate, composed largely of bowlders of serpentine. The formation ranges from beds 400 or 500 feet thick in the southern part of the region to a thin bed, finally disappearing, along the front of the hills northeast of Ciervo Mountain. It does not reappear north of that point nor to the west, in the Vallecitos or Panoche regions.

UPPER MIOCENE.

The formation last described is overlain by a thick mass of unfossiliferous beds which are the northward continuation of the fossil-bearing Jacalitos and Etchegoin formations of the Coalinga district. Owing to the lack of fossils in the Cantua-Panoche region these formations are not separable. The gradual thinning and final disappearance of the underlying fossiliferous middle Miocene beds as the monocline at the border of the valley is followed northwestward beyond Cantua Creek, just as they disappear when followed southward to Pleasant Valley in the Coalinga field, indicates that the Jacalitos and Etchegoin formations are unconformable on the underlying formations. The base of the upper Miocene is assumed to be marked by the base of a zone of alternating greenish and reddish-brown gravel, sand, and clay which rest directly on the early Miocene beds near the mouth of Tumey Gulch and in the Vallecitos. Strata of this character, together with a variety of other beds, form, roughly speaking, the equivalent of the Jacalitos formation, or the lower half of the upper Miocene, the upper half being made up of blue and gray pebbly sand and sandstone beds equivalent to those of the Etchegoin formation of the Coalinga district, interbedded with and overlain by variable sandy strata and dark or earthy brown clays. In the Vallecitos the upper beds in the syncline that forms the valley are supposedly of upper Miocene age, and there the dark and varicolored impure clays are predominant. The thickness of the upper Miocene is at least 3,000 feet.

PLIOCENE.

The summit of the Tertiary system in the Cantua-Panoche region is composed of conglomerate, sandstone, clay, and incoherent gravel and sand, forming the continuation of the beds in the northern part of the Coalinga district mapped as the Tulare formation. These beds are entirely unfossiliferous and in general not very different from the Miocene rocks, so that their separation from the underlying formations is difficult. In fact, they are so lacking in constant distinguishing features that they can not be definitely recognized as the equivalent of the typical Tulare in the Kettleman Hills, Coalinga district, nor be set off as a well-defined stratigraphic unit. It is believed, however, that they represent a portion of the Tertiary later than the Miocene, that they are approximately equivalent to the Tulare formation, and that they are partly at least nonmarine in origin. This formation outcrops along the border of the hills facing the San Joaquin Valley, where it dips at a moderate angle and has a thickness of at least 700 feet, or probably more. In the region of the two Panoche creeks coarse and fine varicolored material, supposedly equivalent in age, forms a mantle of low-dipping beds unconformably overlying the Franciscan formation, the Cretaceous, and locally the older Tertiary strata.

QUATERNARY FORMATIONS.

In addition to the formations of the stratified series so far described, mention should be made of material of comparatively recent origin, such as the alluvium that covers the floor of the Great Valley and of Panoche Valley, old stream gravels that appear as a cap on numerous stream-cut terraces at levels up to several hundred feet above the present channels, and the soil that forms a thin veneer over portions of the hills.

IGNEOUS ROCKS.

The rocks of the Cantua-Panoche region are almost entirely sedimentary in origin. Aside from the serpentinous basic intrusive rocks already described as associated with the Franciscan formation the only igneous rock that has been discovered in place in the area mapped is a small intrusion of basalt in the early Miocene beds on the north side of the Vallecitos. This occurs only in one small patch at an elevation of 2,100 to 2,300 feet in the SW. ¼ sec. 29, T. 16 S., R. 11 E., 2 miles north of the divide between the east and west portions of the Vallecitos. The basalt is intruded parallel to the bedding of the lower Miocene sandstone nearly at the contact of that sandstone with the overlying varicolored, supposedly upper Miocene clay. There is no positive evidence of the date of the igneous activity indicated by this intrusion further than that it was not before the period of deposition of the lower Miocene beds, but it probably took place during the early part of the Miocene. More extensive areas of basaltic rocks occur southwest of Panoche Valley, just outside of the region mapped. The date of these intrusions and flows probably coincides with that of the basalt in the Miocene of the Vallecitos.

POSSIBLE OCCURRENCE OF OIL.

GEOGRAPHIC DISTRIBUTION.

It is now proposed to discuss briefly the areas in the Cantua-Panoche region that may possibly contain petroleum and to determine, by considering the various geologic factors, such as the lithology of the beds and the structure, how favorable or unfavorable are the conditions in each area for the occurrence and accumulation of oil. For an undeveloped region such as this, in which the character of the rocks makes it not impossible for oil to be present, but which for the most part has not been subjected to experimental test by the drill and in which the local tests made have been inconclusive, it is of course impossible to reach positive conclusions as to the occurrence of oil in commercial quantities at depths. Tentative conclusions of distinct value, however, may be reached by means of careful studies of the geologic features, and comparisons with oil regions in which the conditions of accumulation are known. Such studies should precede the work of the operator. The statements here made regarding the possibility of obtaining oil in the several areas into which the Cantua-Panoche region has been divided are the personal opinions of the writer based on such studies. It is planned to publish a topographic and geologic map at a later date, with a more detailed account of the geology, from which the reader may judge for himself of the validity of the conclusions here expressed.

In the Coalinga oil district, which adjoins the Cantua-Panoche region on the south, there are two main varieties of petroleum, which occur at different horizons. A paraffin oil of light gravity occurs in the purple shale of the Cretaceous and is believed to have originated there. This is the highest member of the Upper Cretaceous series in the north end of the Coalinga district. This oil is obtained from sands which are contained in the purple shale. The second variety of petroleum, which furnishes, roughly speaking, 99 per cent of the total production, is a heavier, asphaltic oil and is obtained in vast quantities from the sandy Miocene strata immediately overlying the supposed Eocene diatomaceous shale, which is tentatively classed in the Coalinga report as the upper member of the Tejon formation. This oil is believed to have originated in this shale, and the Miocene beds are productive only where they are closely associated with it. The same formations that contain the oils of the Coalinga district continue throughout the Cantua-Panoche region and are locally petroliferous. Their occurrence and character and the general geology of this region support the view regarding the origin of the oil expressed in the report on the Coalinga district [a] and give ground for the belief that any oil found in the northern region will occur in association with one or the other of these formations.

In considering the possibility of obtaining oil in the region a number of different belts or areas occupied by these formations will be discussed separately. Areas of rocks not belonging to or not closely associated with these formations need not be considered.

The areas to be considered are the following:

1. The outcrop of the Eocene (?) white shale extending along the outer foothills from the north edge of the Coalinga district to a point 2 or 3 miles northwest of the mouth of Big Panoche Creek, where it becomes completely hidden beneath the late Tertiary beds at the border of the valley.

2. The outcrop of the purple shale of the Upper Cretaceous series extending in a fairly direct line from the north edge of the Coalinga district to the vicinity of New Idria and beyond.

3. The area northwest of Ciervo Mountain where the purple shale passes beneath the later formations in the axis of the Ciervo anticline. In this connection will be discussed also the outcrops of the purple shale extending from that area westward along the south flank of this anticline to Silver Creek, and northwestward from the north flank along the outer foothills nearly to the mouth of Little Panoche Creek.

4. The outcrop of Eocene (?) and Miocene beds east of San Carlos and Silver creeks at the east end of the Vallecitos.

5. The outcrop of Cretaceous and Tertiary beds along the north side of the Vallecitos.

6. The outcrop of the Cretaceous-Tertiary formations on the south side of the Vallecitos.

FIRST AREA.

The belt of outcrop of the supposed Eocene white shale and overlying Miocene beds along the outer foothills is a regular continuation of that occupied by the productive wells of the Coalinga East-side field. The beginning of this belt is on the Coalinga anticline, where the Miocene beds overlying the white shale are productive for several miles. At first appearances the presumption would seem to be in favor of the productiveness of these same beds continuously northwestward from the northern portion of T. 19 S., near the north end of the area mapped in the report on the Coalinga district, to the point where they disappear north of the mouth of Big Panoche Creek, but the facts do not seem to warrant this presumption.

Several wells drilled along this belt within a distance of 5 miles northwest of the most northerly producing wells of the Coalinga dis-

[a] Arnold, Ralph, and Anderson, Robert, Geology and all resources of the Coalinga district, California: Bull. U. S. Geol. Survey No. 398, 1910.

trict and all the wells south of Salt Creek have shown that the Miocene sands which form the reservoirs of the oil farther south are here unproductive. The barrenness of these beds is probably to be accounted for by the steepening of the dip of the monocline (from about 20° to 30°) that takes place near the northern edge of the Coalinga district. It should be noted likewise that just south of the northern line of T. 19 S. there is, coincident with the steepening of the dip, a decided change in the strike of the formations from a north-south direction in the Eastside field to a northwest direction from that field toward Cantua Creek. This indicates that the beds south of this change in strike form in reality a broad summit for the eastward-plunging Coalinga anticline, which protrudes outward from the mountains and has its axis unsymmetrically placed near the southwest limb of the fold. The productive oil sands of the Eastside field are confined to the low-dipping beds over this broad summit of the anticline. It is probable that at one time the steep beds bordering the San Joaquin Valley arched over Joaquin Ridge, forming a covering for the higher portion of the Coalinga anticline. The oil that was originally contained in these steeper beds doubtless rose from them into the summit of the fold and was subsequently lost when this covering was eroded.

The northwestward continuation of the belt, from Salt Creek to Panoche Creek and beyond, is of the same steeply dipping, truncated type. The outcrops of the Eocene and Miocene formations in this belt show no seepages of oil, although the white diatomaceous shale gives local indications of having probably at one time been impregnated with petroleum. It is believed that if oil were present at depths in large quantity in such steeply dipping strata its presence would be made known by seepage at the exposed edges of the beds, as it is all through the Coalinga district, along the south side of the Vallecitos in this region, and elsewhere. However, it can not be stated to be impossible that oil may have been retained in the strata where they dip at a low angle beneath the edge of the San Joaquin Valley, even though there is no marked evidence of it at the outcrop, where they are steeply inclined. Throughout the belt the beds dip northeastward toward the valley, but this dip gradually decreases near the border of the hills as if they flattened out under the valley. South of the mouth of Tumey Creek the minimum depth to the base of the Miocene along the very fringe of the plain, where the beds have a dip of 5° to 12°, would be 4,500 feet. Near the point where Big Panoche Creek debouches upon the plain and thence south to the mouth of Tumey Creek the inclination of the strata is low, and a well drilled even some distance out on the valley floor would reach the basal Miocene at a less depth than this. It would need to be placed away from the hills in order to reach the basal Miocene at a sufficient depth to give an adequate test. In this connection it should be noted that the purple shale of the Cretaceous is separated from the Miocene by a stratigraphic thickness of only about 2,500 feet near the mouth of Panoche Creek, and that this shale here gives signs of being impregnated with oil. In a deep well it would be possible to make a test of the sand lenses overlying this shale and in its upper part, as well as of the Miocene.

SECOND AREA.

The outcrop of the purple shale in the series of Cretaceous beds may be traced continuously along the northeast base of the mountains from Oil City, in the Coalinga district, to New Idria and beyond, a distance of 30 miles or more. The lower concretionary sandstones of the Cretaceous form the face of the mountains, and the stratigraphically overlying purple shale forms a belt of low relief in front of the main mountain ridges and separates them from the parallel belt of high hills and ridges produced by the upper concretionary sandstone, which in turn overlies the purple shale. The purple shale dips rather steeply northeastward throughout the belt. The angle of the dip ranges from about 20° to 90°, or vertical, but it is only locally as low as 20°, the general dip being considerably steeper. The shale has been subjected to much crushing and is faulted at many places.

This shale contains a large amount of petroleum in the Oil City field, at the southeast end of the belt above described, where it furnishes the light oil derived from wells drilled into it near the axis of the Coalinga anticline. At several places between Coalinga and New Idria the shale and the limestone nodules that it contains give a faint odor of petroleum when freshly fractured, a fact which, together with less positive indications, such as discoloration, warrants the conclusion that the beds were at one time impregnated throughout their extent.

In Mancillas Canyon, 6 miles northeast of New Idria, along the continuation of this outcrop, there is said to have been formerly a strong seepage of oil, but when the locality was visited by the writer the outcrops had become covered by landslides. The Fresno-San Benito well was drilled at this place (near the center of the line between secs. 20 and 21, T. 17 S., R. 11 E.) about eight years ago, to a depth of several hundred feet, without success. The beds penetrated by the drill are thought to belong in part to the purple shale, but they are tilted, crushed and faulted and the stratigraphic relations are not clear. The conditions for the accumul tion of oil at this locality are poor. One other well has been drilled along this belt of the purple shale and has furnished a partial test of an area that is probably as favorable as any other along the belt under consideration. This is the Cantua well, situated in a branch ravine of Cantua Creek on the east side of sec. 35, T. 17 S., R. 13 E. It started near the top of the purple shale, at a point where the monocline is regular and dips at angles of 25° to 30°, and penetrated the sands at the base of the shale at a depth of a little more than 2,000 feet without obtaining oil. No test has been made of the beds at the top of and immediately overlying the purple shale, in which a small amount of oil may have collected.

The conclusions regarding this area are similar to those regarding the steep beds in the area first discussed and are based on the same grounds. Oil is found in the comparatively low-dipping purple shale near the summit of the Coalinga anticline but will be found in decreasing amount toward the northern edge of the Coalinga district as the distance from the axis of the anticline and the angle of the dip increase. It is believed that this belt will be found unproductive, or productive of only small amounts of oil, throughout its extent in the Cantua-Panoche region.

THIRD AREA.

The Ciervo anticline is an oblique offshoot of the main structure of the Diablo Range similar in type to the Coalinga anticline. It is probable that in the late Tertiary or early Quaternary period its summit was covered for many miles by the Tertiary formations and that large accumulations of oil occurred along it. In the course of time, however, the oil-bearing formations have been worn away from the major portion of this anticline, leaving the underlying unproductive Cretaceous sandstone exposed in wide belts on both sides of the axis. The only place where beds as young as the oil-bearing shales remain over the axis of the fold is at its eastern end, where it plunges steeply and changes into a monocline in the Miocene beds of the foothills. At this plunging end it is covered by the purple shale, the overlying upper concretionary sandstone at the top of the Cretaceous, and the succeeding Eocene formation. The area embracing this end of the anticline will here be discussed.

Its structural features are analogous to those of the plunging end of the Coalinga anticline, which has proved so productive, and the chance for the presence of oil in the beds deserves careful consideration. No adequate test by means of a well has been made anywhere in the vicinity. A well named the Ohio is reported to have been drilled many years ago to a depth of 1,800 feet in the SE. ¼ sec. 22, T. 16 S., R. 12 E. It started in the purple shale on the south side of the Ciervo anticline and got no oil.

The Cretaceous purple shale is exposed over an area of several square miles near the axis of the Ciervo anticline in secs. 14, 15, 21, 22, and 23, T. 16 S., R. 12 E., and passes beneath later beds along the summit of the fold in the SW. ¼ sec. 24, the northwest corner of sec. 25, and the N. ½ sec. 26 of the same township. The area near the summit of the fold in which the purple shale is within reach of a drill passing down through the overlying formations lies mainly in the following sections:

Secs. 24, 25, 26, 35, and 36, T. 16 S., R. 12 E.
Secs. 19, 29, 30, 31, and 32, T. 16 S., R. 13 E.
Secs. 1 and 2, T. 17 S., R. 12 E.
Secs. 5 and 6, T. 17 S., R. 13 E.

The purple shale in the Ciervo anticline gives the appearance of having been thoroughly impregnated with petroleum. It is characterized by the blackish-brown discoloration and strong sulphurous odor that seem to result from the presence of oil in the shale of this type in many places, and lenses of sand that occur within it are stained brown and give off a marked petroleum smell. These features easily escape notice owing to the weathered nature of the exposures, but the appearance of fresh specimens of the rock leads to the belief that the formation is soaked with oil throughout and that a considerable amount of free oil might be found in the beds at greater depth, away from the surface zone of weathering and evaporation. The light oil found in the purple shale at Oil City, and at the Union wells north of the west end of the Vallecitos, which appears to be characteristic of this horizon, is of a type that would not be expected to leave at the surface as marked evidences of its presence as the asphalt oil in the Miocene of the Coalinga district and other parts of California.

If the formation contains as large an amount of oil as is believed, the question remains whether the oil is too much disseminated through many hundred feet of beds to be obtainable in commercial quantity, or whether some of it has accumulated in reservoirs that may be profitably tapped. There can be no doubt that a large amount has been lost by dissemination through the beds and escape at the surface, as is attested by the prevalence of the oil discoloration throughout the formation. But it is an important fact that thick lenticular beds of porous, fine-grained sand which ought to make good reservoirs are inclosed within the shale. It is highly probable that much oil has been absorbed by these lenses and retained in them. These lenses are not confined to any particular part of the shale but occur in its upper as well as its lower portion and would be found somewhere within the shale in any section that might be made of it. Some of the lenses attain a thickness of 100 feet or more. The body of oil-bearing beds of which the purple shale is the chief constituent is likewise overlain by sandy strata in which, it might be expected, accumulations of oil would take place. The petroliferous beds dip at an angle of only a few degrees beneath the later formations on the summit of the Ciervo anticline, and wells drilled down through the later beds at a considerable distance from the outcrop of the purple shale would be best calculated to reach the shale and its included sands at a depth at which the petroleum contents would be sealed in and preserved intact.

A good situation for a test well would be about 2 miles northwest of Ciervo Mountain.

The dip of the beds in the Ciervo Mountain region is low and the structure is undulating, and it is not impossible that some of the minor folds might aid in the concentration and confinement of a local body of oil. In this connection it is worthy of note that a number of small faults occur in the Tertiary beds in this region which have not brought to light any oil through seepage; but in the mind of the writer this fact does not carry great weight as against the favorable conditions mentioned. The conclusion reached is that the area on and adjacent to the Ciervo anticline offers possibilities worth testing. It is believed that a well drilled near the summit of the anticline as suggested would have a fair chance of obtaining a light oil in paying quantity. This much, at least, may be said—that the conditions are more favorable than those in many places where wild-cat wells are being drilled in California outside of the developed fields.

As regards the belts of purple shale extending from the axis of the Ciervo anticline westward on the south flank of the fold to Silver Creek and northwestward on the north flank nearly to the mouth of Little Panoche Creek, the conclusion is that these areas do not show great promise. This conclusion is based on the fact that these belts have unfavorable structural features similar to those mentioned in discussing the first and second main areas—that is, they consist of belts of strata dipping at a medium or a steep angle in one direction. The shale looks as if it had been oily, and it probably does contain oil below the surface. This probability, together with the presence in the shale of lenses of sand like those above mentioned on the anticline, makes it likely that a small quantity of oil might be obtained from these beds if they were tapped at a reasonable depth where covered by the later beds, especially where the dip is not steep and the disturbance not too great. A location for a possible test at the edge of the San Joaquin Valley near the mouth of Panoche Creek has already been mentioned in connection with the first area discussed. There the purple shale would probably be found lying at a low angle, although at a great depth below the surface. Back in the hills toward the outcrop of the purple shale where a well is now being drilled, the dip steepens and the conditions are less favorable. In the section dealing with the purple shale north of the west branch of the Vallecitos, in the fifth area, conclusions will be expressed regarding an area with structural conditions similar to those prevailing in the belts of shale under discussion. If oil is present in these belts as abundantly as in that area, which is not improbable, the lower dips appearing locally in these belts would warrant a conclusion concerning them slightly more favorable than for that area.

FOURTH AREA.

The area to be considered next is that directly east of San Carlos and Silver creeks, at the east end of the Vallecitos, where the Eocene (?) diatomaceous shale and the overlying lower Miocene sandstone and shale are exposed. These formations are brought to the surface by the rising end of the Vallecitos syncline and occupy crescent-shaped belts that curve around the end of the valley. The dip of the beds is invariably in toward the valley and ranges from 5° to 30°. The structure is not very favorable for the accumulation of oil, and yet oil might accumulate here if any considerable quantity existed in the beds. The lower Miocene sandstone and shale lie unconformably upon the Eocene (?) shale, as they do in the Coalinga field, and if oil were present in the shale it should rise and collect in the sandy strata overlying their truncated edges and make itself apparent at the outcrop. Where these overlying beds are exposed in the southern part of the area, just north of San Carlos Creek and in the sharpest portion of the Vallecitos syncline, no sign of such an accumulation was discovered, and there seems little basis for a favorable opinion regarding this portion of the area. However, a good seepage of oil in beds of early Miocene age occurs at the northern edge of the area here marked off, on Silver Creek, as will be described below, and possibly the rocks are oily in other places in the northern part of this area, where the low hills are covered with terrace deposits and the formations are poorly exposed. The low-dipping Miocene strata in this vicinity may therefore possibly be considered oil bearing, but any definite judgment of its productivity should be deferred until a test is made in the more favorable area immediately across Silver Creek, to the northwest, to be discussed next.

FIFTH AREA.

The range of high hills separating the Vallecitos from Big Panoche Valley is formed, as before stated, by the Ciervo anticline, the axis of which there runs entirely through Cretaceous sandstones that are older than the purple shale and are therefore of no importance in connection with oil. The southern half of this group of hills marks the southern flank of the anticline, on which are exposed in turn the several possible oil-bearing formations, which dip south-southeastward into the Vallecitos. The Vallecitos (the "little valleys") is structurally one synclinal valley but is separated by a low divide into an eastern part which drains into Silver Creek and a western part which drains through Griswold Canyon to the Panoche Valley. Although the series is continuous along the north side of both divisions, the geologic features in the two parts are somewhat different and they may therefore be discussed separately.

Area north of east branch of the Vallecitos.—The eastern end of the area on the north side of the Vallecitos appears to be the most promising oil territory in the Miocene of the Cantua-Panoche region, for it is the only part of the region in which the Miocene beds are known to contain oil where the structure is favorable for its accumulation. The area should be tested, and the writer would recommend that a test well be drilled a short distance north of John Ashurst's place, at a point where the basal Miocene oil sand could be reached at a depth of 800 to 1,200 feet. If the test proved that the sand is productive a considerable area of this section and the sections adjoining on the northwest, north, and northeast, covered by the surface outcrop of the lower and upper Miocene beds, could reasonably be regarded as oil land.

The formations overlying the concretionary sandstone that forms the summit of the range between the Vallecitos and Panoche Valley are the purple shale and upper concretionary sandstone of the Cretaceous, the Eocene or Cretaceous dark clay, the Eocene white sandstone, the Eocene (?) diatomaceous shale, the lower Miocene sandstone and shale, and a very thick mass of upper Miocene variegated clay. The formations below the Miocene partake of the general southward-dipping structure but are steeply dipping, broken, and inconstant in area, their minor structure and distribution being difficult to make out. The purple shale thins to an insignificant zone within 2 miles west of Silver Creek and its steep and disturbed structure is unfavorable for the presence of oil in quantity. The known seepages of oil in this region are in the lower Miocene beds, and it is in them that oil must be sought. These beds lie with pronounced unconformity upon the older formations and form just west of Silver Creek a low-dipping structure in which the chances for the accumulation of oil are good. An outcrop of very oily sand occurs at the base of the lower Miocene along Silver Creek, in the west part of the SW. ¼ sec. 5, T. 17 S., R. 12 E., just southeast of the New Bedford well, and the beds of this formation are petroliferous at other places in the vicinity.

At the point mentioned the lower Miocene fossiliferous sand and conglomerate lie unconformably upon siliceous shale and interstratified gray sand layers of the Eocene (?) shale formation. These underlying beds are also petroliferous, but the greater quantity of the oil has accumulated in the basal sand of the Miocene along the unconformity. The sand is saturated with oil through a thickness of at least 15 feet and the abundance of the oil gives ground for the belief that this sand contains a large amount of oil at greater depths. The basal zone is of variable texture from place to place, but is made up predominantly of massive, fine, porous sand only locally indurated. The oil is believed to have originated in the underlying thick formation of Eocene (?) diatomaceous shale and to have been collected in the blanket of Miocene sand that overlies these truncated beds. The possibilities are worthy of consideration, however, that some oil may have originated in the lower Miocene beds, in which there is here a considerable proportion of diatomaceous shale, or that it may have come up from the Cretaceous purple shale.

The lower Miocene contains hard sandstone beds that may easily be traced along their outcrops because they form the first high ridge parallel with the Vallecitos on its north side. The formation is 700 to 800 feet thick and consists of the basal zone, about 100 feet thick, of variable sandy, gravelly, and shaly beds; an overlying zone, about 100 feet thick, of siliceous diatomaceous shale; and a main upper portion, over 500 feet thick, composed chiefly of sandy strata with some interbedded shale and containing two prominent hard sandstone beds in its central part, each about 100 feet thick. The lower sandy zone may prove to be a productive oil sand. It has the thickness and lithologic qualities that would make it an excellent reservoir were oil present in large quantity. Furthermore, the overlying flinty shale ought to serve as a cap to prevent most of the oil from rising into higher beds. The escape of the oil along the bedding planes would be hindered by the lowness of the dip and by the tendency of the oil to seal itself in by the deposition of solid residue near the surface. The dip of the lower Miocene beds within about a mile west of Silver Creek is slightly variable, but on the average it is only about 8° toward the southwest. Locally there is a tendency toward flattening, affording small wrinkles that may be a factor in helping to hold the oil. The dip is sufficiently low to make the basal portion of the Miocene beds accessible within a reasonable depth, even to the axis of the Vallecitos syncline.

About 2 miles west of Silver Creek there is a rapid steepening of dips in the Miocene beds to 20°, 30°, and finally 45° or more. For several miles beyond this point they preserve a low dip on the summit of the ridge, but they fold over abruptly into the steep dips on the southern side. The steepness of these dips, combined with the lack of evidence of oil in the beds, leaves little hope of their productiveness except at the eastern end of the area north of the east branch of the Vallecitos.

The area here under discussion has not been properly tested. The only well drilled—the New Bedford well—is situated just west of Silver Creek, near the point where the oil sand outcrops. It started in the lower part of the Miocene and has been drilled at great expense to a depth of 1,720 feet, into the underlying formation. This well struck the oil sand that outcrops on Silver Creek at a shallow depth and found it oily, but obviously the boring is too near the outcrop of the lower Miocene sand to obtain any appreciable production from it. Oil is said to have been struck at about 1,720 feet, which would probably be near the base of or below the Eocene sandstone, but this report has not been substantiated.

In conclusion it may be said that the area of Miocene beds at the east end of the Vallecitos, within about 2 miles west of Silver Creek and north of the Vallecitos syncline, has a good chance of being productive. Whether or not the oil, traces of which appear at the surface, exists in the beds in paying quantity can be determined only by the drill, but the writer inclines to the belief that wells drilled into the lower Miocene beds at some distance from their outcrop will prove to be productive.

Area north of west branch of the Vallecitos.—The general structure and the succession of beds already described continue all the way along the north side of the Vallecitos, although locally one member or another of the pre-Miocene formations may not appear, owing to its pinching out, to overlap of the lower Miocene, or to faulting. All along the north side of the west branch of the valley dips of 35° to 60° prevail and the beds are somewhat faulted, so that the conditions for the accumulation of petroleum are poor. In addition, it should be noted that intrusive basalt penetrates the formations at least as far up as the summit of the lower Miocene sandstone and shale. The basalt appears about 2 miles north of the divide, between the two arms of the Vallecitos, as a small intrusion parallel to the bedding near the contact of the lower Miocene with the overlying upper Miocene clay. It is the only known evidence of igneous activity later than Jurassic or early Cretaceous time within the region studied. No indication of oil has been discovered in the Eocene (?) or lower Miocene formations, and hence there is no recurrence here in the Tertiary beds of either of the more favorable conditions of the eastern end of the area just described. In the purple shale member of the Cretaceous, however, important seeps of oil occur, and wells drilled into it have obtained petroleum in small quantities. These seeps appear in the upper beds of the purple shale in the canyon of the Union Oil Company's wells west of the stage road to Panoche, which follows down Griswold Canyon.

One of the seeps is near the Union wells, about one-half mile east of the stage road, in the NE. ¼ sec. 24, T. 16 S., R. 10 E. There the ground overlying the purple shale for 200 feet or more along a side gully is soaked with oil and a pool of black oil gathers when a small hole is dug. This seepage is believed to be along a fault traversing the Eocene and Cretaceous beds in a northwest-southeast direction. A number of wells were drilled several years ago in the immediate vicinity of the seep and obtained small quantities of oil, but the wells were shut down.

Another large seep is located nearly a mile farther east up the same canyon, northeast of the center of the NW. ¼ sec. 19, T. 16 S., R. 11 E. There the oil has risen in large quantity to the surface of the clay shale at the top of the purple shale, and the way the light oil gathers when a hole is dug indicates that it is still rising. It is said that this seep has been known for about thirty years. Some years ago a well was dug at the seep by Daniel McDonald to a depth of 60 or 70 feet and several barrels of oil now stands in the bottom of this well. A smaller seepage occurs at the base of the overlying sandstone in the same canyon halfway between the dug well and the Union wells.

The oil is dark brown and is comparatively light and fluid. It emits a pleasant odor and the seeps remind one in this respect and in general appearance of those in the Oil City area in the Coalinga district. In fact, the formation here is the continuation of that at Oil City and the oil has doubtless had the same origin. The structure, however, is different, for in the Oil City locality the beds have a much lower dip and are folded into an anticline, whereas here they have a steep dip in one direction. The character of the oil is indicated by the fact that at these seeps no large quantity of asphalt has been deposited.

An analysis of the oil from the dug well, made by Walter Stalder and kindly furnished by Doctor Cottrell, of the University of California, shows that it has a gravity of 23° to 24° Baumé and is of grade intermediate between a true paraffin oil and an asphalt oil. In this respect it is like the asphaltic paraffin oil of Oil City.

Below the horizon of the seeps the purple shale is impregnated with oil through a thickness of many hundred feet. The thickness of the shale is, roughly speaking, about 1,000 feet, and it is oily practically throughout. It contains a number of large lenses of fine-grained gray and yellowish sandstone much like that typical of the concretionary members below and above, and these lenses might be expected to form local reservoirs for the oil at depths. The upper concretionary sandstone of the Cretaceous system immediately overlies the shale and is impregnated with oil in its basal layers. The resulting discoloration has been noticed through a thickness of 30 feet of the sandstone, but no sign of the oil having penetrated farther up was noticed. Under good structural conditions this basal zone might make a fair oil sand, although it seems rather to have acted as a barrier and caused seepages to rise from the shale at the contact. The shale is crushed and disturbed, as usual, but the general structure is that of a southward dip at an angle of about 45°.

It is believed that this steep dip and the dissemination of the oil through so great a thickness of shale preclude the hope that these beds may be richly productive, although it is probable that they may yield a small production which will assume economic importance at some future time, especially in view of the good quality of the oil. It is not impossible that oil may be found in paying quantities at the top of the shale and in sand lenses entirely sealed within it. The area to which these conclusions apply lies in the N. ½ sec. 19 and S. ½ sec. 18, T. 16 S., R. 11 E., and the NE. ¼ sec. 24 and S. ½ sec. 13, T. 16 S., R. 10 E. Farther east the purple shale is reduced to a thin zone, seeming to be almost entirely replaced, through lithologic change, by concretionary sandstone. In an easterly direction it does not afford promising territory for the production of oil. In a westerly direction the sections named extend to Griswold Canyon, the western limit of the region studied. The same steep dip of the Cretaceous and later beds continues westward from Griswold Canyon along the north side of the valley of Pimental Creek.

SIXTH AREA.

Along the south side of the two branches of the Vallecitos the mountains and the descending ridges are formed by a continuous series dipping steeply toward the valley. This is the southern arm of the Vallecitos syncline. From San Carlos Creek, at the eastern end of the Vallecitos, it strikes westward for about 5 miles and then bends at an angle of about 35° and strikes northwestward to the western end of the Vallecitos. Beyond that the same steep series continues in about the same direction along the south side of the valley of Pimental Creek. The main mountain ridge is formed of Cretaceous sandstone that lies stratigraphically below the oil-bearing formation. The area of chief interest in the present connection is the belt of Tertiary strata at the outer edge of the foothills. These consist of the Eocene (?) shale and the lower Miocene sandstone and shale at the edge of the hills, overlain by the thick formation of upper Miocene variegated clay. South of the eastern portion of the Vallecitos these strata are underlain by the Eocene white sandstone and the several members of the Upper Cretaceous, but south of the western portion complicated structural conditions are present, the belt of Eocene white sandstone bends southward and disappears, and the Eocene (?) shale is underlain by a great thickness of beds of doubtful age. The beds last mentioned consist in large part of petroliferous siliceous shale similar to the Eocene (?) shale and the Cretaceous purple shale, and it is very difficult to determine where to draw the line between them if both formations are represented.

The dip of the early Miocene and older beds ranges from about 40° to 90°, or vertical. For much of the way these beds are overturned along the front of the hills and appear to dip southward. The overturning, however, is not believed to extend very far below the surface. The overlying upper Miocene clay is likewise steep along its contact with the lower Miocene, standing vertically in places and nowhere dipping less than 30°. The dip decreases, however, northward toward the axis of the Vallecitos syncline.

The Eocene (?) shale and the lower Miocene are oily practically throughout their extent along the south side of the Vallecitos, the siliceous diatomaceous shale of the former and similar material interbedded with the latter being impregnated with oil, so that when broken at almost any point they give off a strong odor of petroleum. The sandy strata of the lower Miocene are also locally impregnated where they lie in contact with this shale. At a number of places the oil actually oozes out of the beds; these seeps have induced persons to drill wells near by. The following examples of such seeps and wells may be mentioned. In the canyon of the Hamiltonian well, 1½ miles south of John Ashurst's place, north of the center of sec. 24, T. 17 S., R. 11 E., oil rises to the surface out of the overturned and broken strata near the contact between the Eocene white sandstone and the overlying Eocene (?) shale. It doubtless has its source in the shale. The Hamiltonian well was drilled without success about 1,500 feet into the stratigraphically underlying although, owing to the overturn, apparently overlying Cretaceous beds. Another seep in the Eocene (?) shale is in the creek bed in the SE. ¼ sec. 16 of the same township. No well has been drilled here. A third seep is in the canyon of the San Carlos well, near the center of sec. 8 of this township. There and in the next small canyon to the northwest oil seeps out of the same belt of shale and also appears abundantly impregnating the lower Miocene sandstone and shale throughout their thickness. The San Carlos well, which was drilled by hand to a depth of approximately 170 feet about sixteen years ago, attracted some attention to this region. It is in the oily shale and gradually fills up with oil in the course of a few hours when bailed out. In this way it might produce from 1 to 5 barrels of oil a day, but its capacity has never been properly tested. The oil is of light gravity and very good quality. The Riley well was drilled nearly one-half mile north of the San Carlos well in the same section several years ago. It started near the top of the steeply dipping lower Miocene beds and went down 1,200 to 1,500 feet without finding oil.

Another good seep appears at the summit of the Eocene (?) shale in a canyon at the west side of the SE. ¼ sec. 6, in the same township, and still another about a mile north-northeast of the last-mentioned locality, in the southern part of sec. 31, T. 16 S., R. 11 E. At this place the beds stand vertical and oil rises out of the upper Miocene clay several hundred feet above the top of the lower Miocene sandstone and shale. Here the Ashurst Oil Company put down two or three wells, the deepest of which was between 600 and 900 feet deep, and got a showing of oil and gas. The well could not have reached the lower Miocene oil sands at this depth. The only other well along this belt bordering the south side of the Vallecitos which was drilled to any considerable depth was the Calistoga well, which is said to have gone down to a depth of about 1,000 feet in the upper Miocene clay on the terrace in sec. 18, T. 17 S., R. 12 E., about a mile southeast of John Ashurst's place, and to have obtained considerable gas. It probably did not reach the lower Miocene sands. The Fresno-San Benito well, which was drilled in Mancillas Canyon farther back in the hills south of the Vallecitos than the belt along the border of the hills here being discussed, is mentioned on page 71 in connection with the second main area.

The foregoing brief account of the wells along the south side of the Vallecitos shows that none of them afforded a thorough test of the area. Most of them were placed too near the outcrop of the oil-bearing beds to reach any large body of oil and the rest were not drilled deep enough to give satisfactory tests. The oil prospects of the area are as much in doubt as if these wells had never been drilled. The geologic criteria indicate that the beds stand too steep to retain oil in large quantities. The beds are undoubtedly rich in petroleum, but the oil seems to have become disseminated and to have risen freely to the surface through a great thickness of strata rather than to have been concentrated in any particular porous stratum and held there. It is quite likely that wells started at some distance from the outcrop and carried down to the lower Miocene sandstone and shale, or to the underlying shale at a considerable depth, would yield a small quantity of oil, especially if they were drilled where the monocline is not so steep as it is along most of its course. In the opinion of the writer, however, such wells would not under present conditions obtain oil in paying quantities.

The dip of the beds gradually decreases northward toward the axis of the Vallecitos syncline, especially in the central and eastern portions of the valley, and it is possible that they retain a larger quantity of oil in their low-dipping portion than they do where they are steeper. In this connection, however, the possibility that water may occupy the oil sands in the trough of the syncline must be considered, although no direct evidence is obtainable on this point, and also the fact that the depth to the lower Miocene sandstone and shale increases rapidly. The upper Miocene clay is at least 3,000 feet thick in the central portion of the valley. Its thickness decreases toward the eastern end of the valley, where the syncline rises and the upper part of the formation has been removed. It is not believed that the lower Miocene sandstone and shale would be out of reach of the drill at any point in the valley, but it is questionable whether the slightly more favorable conditions for the presence of oil at some distance out from the hills would now warrant the expenditure necessary for a test in this deep territory.